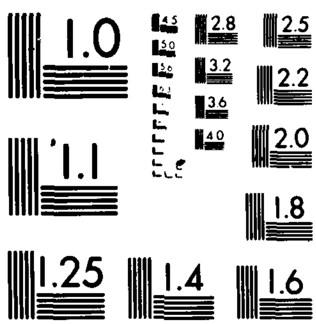
AD-A114 775 RAND CORP SANTA MONICA CA F/G 1/5
AN INTRODUCTION TO THE TSAR SIMULATION PROGRAM. MODEL FEATURES --ETC(U)
FEB 82 D E EMERSON F49620-82-C-0018

UNCLASSIFIED RAND/R-2584-AF NL

END
DATE FILMED
6-82
DTIC



MICROCOPY RESOLUTION TEST CHART

An Introduction to the TSAR Simulation Program

Model Features and Logic

Donald E. Emerson

February 1982

The research described here was sponsored by the Directorate of Operational Requirements, Deputy Chief of Staff/Research, Development, and Acquisition, Hq USAF, under Contract F49620-82-C-[illegible]. The United States Government is authorized to reproduce and distribute reprints for governmental purposes notwithstanding any copyright notation hereon.

Library of Congress Cataloging in Publication Data

Emerson, Donald E. (Donald [illegible]), 19[illegible]-
An introduction to the TSAR simulation program.

"R-[illegible]-AF."
1. Aeronautics, Military—Data processing.
2. Aeronautics, Military—Mathematical models. 3. Air bases—Data processing. 4. Air bases—Mathematical models. I. United States. Air Force. II. Title.
III. Title: Introduction to the T.S.A.R. simulation program. IV. Title: TSAR simulation program.
[illegible] 358.4'[illegible]'0724 82-[illegible]
ISBN 0-8330-0[illegible]-2 AACR2

Published by The Rand Corporation

R-2584-AF

An Introduction to the TSAR Simulation Program

Model Features and Logic

Donald E. Emerson

February 1982

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
SANTA MONICA, CA. 90406

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER R-2584-AF	2. GOVT ACCESSION NO. AD-A114 775	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Introduction to the TSAR Simulation Program: Model Features and Logic		5. TYPE OF REPORT & PERIOD COVERED Interim 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Donald E. Emerson		8. CONTRACT OR GRANT NUMBER(s) F49620-82-C-0018
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Rand Corporation 1700 Main Street Santa Monica, CA. 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Requirements, Programs & Studies Group (AF/RDQM) Ofc, DCS/R&D and Acquisition Hq USAF, Washington,D.C. 20330		12. REPORT DATE February 1982 13. NUMBER OF PAGES 57
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

No Restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Simulation
Monte Carlo Method
Logistics Operations
Logistics Management
Military Facilities

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See Reverse Side

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TSAR is a complex Monte Carlo simulation of a system of interdependent theater airbases that has been designed for analyzing the interrelations among on-base resources and the capability of the airbases to generate aircraft sorties in a dynamic, rapidly evolving wartime environment. On-equipment maintenance tasks, parts and equipment repair jobs, munitions assembly, and facility repair tasks are simulated for each of several airbases. Asset accounting for each of 11 classes of resources, and for each type within each class, permits assessment of a broad range of policy options that could improve the efficiency of resource utilization on a theater-wide basis. This report first introduces the reader to the scope of the TSAR simulation and to each of the activities that are represented in the simulation. The remainder of the report presents a series of comprehensive discussions of TSAR's logic for each of the types of events simulated.

PREFACE

This report is one of five volumes that collectively document the TSAR and TSARINA computer models developed at Rand to assess the effect of air attacks on the sortie generation capabilities of air bases. These documents are designed with four classes of potential readers in mind:

- Those seeking only a broad overview of TSAR
- Those seeking a full understanding of the logic in the TSAR simulation but wishing to avoid programming details
- Those responsible for preparing input materials and for operating TSAR, and
- Those interested in modifying and extending TSAR logic

The present volume is intended for the first two classes of readers; Sections II and III will probably be sufficient for the first of these. The last two groups will need the three-volume User's Manual.

The TSAR and TSARINA computer models provide an analytic context within which to test a variety of airbase improvements. New passive defenses, new maintenance doctrine, modified manning levels, increased stock levels for parts, equipment, munitions, etc., as well as concepts for improved theater-wide resource management all can be examined for their effect on aircraft sortie generation.

This development was carried out under the Project *AIR FORCE Resource Management Program*; the project was titled "Strategies To Improve Sortie Production in a Dynamic Wartime Environment." These models have been briefed to a variety of Air Force organizations during the development process.

The other four volumes that document these models are:

N-1460-AF, "TSARINA—User's Guide to a Computer Model for Damage Assessment of Complex Airbase Targets," July 1980.

N-1820-AF, "TSAR User's Manual: Vol. I—Program Features, Logic and Interactions," February 1982.

N-1821-AF, "TSAR User's Manual: Vol. II—Data Input, Program Operation and Redimensioning, and Sample Problem," February 1982.

N-1822-AF, "TSAR User's Manual: Vol. III—Variables and Array Definitions, and Source Code Structural Aids," February 1982.

Other documents are planned that will discuss the problems associated with data acquisition for these models and will present the procedures currently under development at Rand to assist in solving those problems.

SUMMARY

TSAR simulates a system of interdependent theater airbases, supported by shipments from the continental United States and by intratheater transportation, communication, and resource management systems. By capturing the interdependencies among 11 classes of resources, this computer simulation will permit decisionmakers to examine the implications of a broad spectrum of possible improvements in terms of their effects upon the sortie generation capabilities of the system of air bases. The simulation also allows examination of the effects of damage inflicted by enemy airbase attacks and by efforts to restore operations.

TSAR is a Monte Carlo event simulation model that has been designed for analyzing the interrelations among on-base resources and the capability of the airbases to generate aircraft sorties in a dynamic, rapidly evolving wartime environment. On-equipment maintenance tasks, parts and equipment repair jobs, munitions assembly, and facility repair tasks are simulated for each of several airbases. Asset accounting for each of 11 classes of resources, and for each type within each class, permits assessment of a broad range of policy options that could improve the efficiency of resource utilization on a theater-wide basis.

TSAR is readily adaptable to problems across a broad range of complexity. When specific features are not needed for the examination of a particular issue, they simply need not be used. Thus, TSAR permits one to represent a single base, a set of independent airbases, or a set of interdependent airbases, without any adjustment or modification of the program. Similarly, the user may not wish to examine the effects of airbase attacks, or may wish to ignore the possible restraints imposed by shortages of aircrews, shelters, ground personnel, equipment, aircraft parts, munitions, TRAP, or fuel. TSAR adapts automatically to all such problem representations.

TSAR has been designed to provide users with an analytic structure within which a rich variety of potential improvements for theater airbases may be tested in a common context. New passive defenses, new maintenance doctrine, modified manning levels, increased stock levels for parts and equipment (etc.) as well as a variety of concepts for theater-wide resource management all can be examined with TSAR in a common context in terms of their ultimate effect on the system's capabilities for generating sorties.

An important objective in the original design formulation was to achieve a sufficiently high speed of operation that the extensive (oft-times trial and error) sequence of runs so frequently necessary in research and analysis would be economically practical. Adaptation of existing models (e.g., LCOM,[1] SAMSOM[2]) was rejected for several reasons, including the extent of the modifications that would have been required and the prohibitive costs that would be associated with their use for problems of the size that were contemplated. The resultant custom-designed TSAR program (written in the widely available FORTRAN language) achieves a substantially higher speed by virtue of more efficient processing and by taking advantage of the recent dramatic increases in the size of the core storage of modern computers. In its current formulation, TSAR makes no intermediate use of auxiliary high-speed storage units (e.g., disks, tapes) except for storing the initial conditions for multiple trials.

ACKNOWLEDGMENTS

The development of the TSAR computer model demanded uninterrupted concentration over an extended period. My debts to the Air Force and to Rand management are obvious. Not so obvious are the debts owed my most understanding family, who endured my total absorption in TSAR's development for over three years.

Among my colleagues at Rand, I would particularly like to acknowledge Louis Wegner and Michael Poindexter for their many helpful ideas and suggestions for dealing with a variety of programming problems, and Milton Kamins and Major John Halliday, USAF, for their ideas that have been incorporated into TSAR logic and for their careful work in creating the data bases that were used throughout TSAR's development.

CONTENTS

FIGURES

TABLES

GLOSSARY

AGE	Aerospace Ground Equipment
AIDA	Airbase Damage Assessment computer model [3]
AIS	Avionics intermediate shops; special test equipment used for repairing avionic LRUs and SRUs
BLSS	Base-level self sufficiency stock of aircraft spare parts
CAP	Combat Air Patrol
CAS	Close air support
CILC	Centralized intermediate logistics concept
CIRF	Centralized Intermediate Repair Facility
COB	Collocated Operating Base
COMO	Combat Oriented Maintenance Organization
CONUS	Continental United States
FIFO	First in first out
FRAG	Fragmentary order that specifies flight requirements
ILM	Intermediate Level Maintenance; on-base parts repair
LCOM	Logistics Composite Model
LRU	Line replaceable unit; an aircraft spare part
NMCS	Not mission capable because spare parts are lacking
NORS	Not operationally ready because spare parts are lacking; same as NMCS
NRTS	Not reparable this station
OST	Order and ship time
POL	Petroleum, oils, and lubricants; often used as an abbreviation for aircraft fuel
POS	Peacetime operating stock; an organization's stock of aircraft spare parts for aircraft maintenance in peacetime
RAM	Rapid area maintenance; special mobile teams used for repairing aircraft battle damage
RR	Flight line maintenance that removes and replaces malfunctioning aircraft parts with serviceable components
RRR	Rapid runway repair
RRR	Flight line maintenance that removes, repairs, and replaces aircraft spare parts (actually, usually removes and replaces with a serviceable unit, and then repairs malfunctioning unit)
SAMSOM	Support Availability Multi-System Operations Model
SCL	Standard combat load that designates the mission dependent munitions to be loaded
SRU	Shop replaceable unit; a component of an LRU
TRAP	Tanks, racks, adaptors, and pylons
TSAR	Theater Simulation of Airbase Resources

TSARINA	TSAR INputs using AIDA
WRM	War Reserve Material
WRSK	Wartime readiness spares kit

I. INTRODUCTION

TSAR is a complex Monte Carlo simulation of a system of interdependent theater airbases that can be supported by shipments from CONUS and by intratheater transportation, communication, and resource management systems. By capturing the interdependencies among 11 classes of resources, this computer simulation permits decisionmakers to examine the implications of a broad spectrum of possible improvements in terms of their effect upon the sortie generation capabilities of the system of air bases. The simulation also allows examination of the effects of damage inflicted by enemy air base attacks and by efforts to restore operations.

The problems that TSAR may deal with can vary quite widely. TSAR may be used for single base analyses or for complex multi-base studies. In practice the available storage capacity of the user's computer, or his fiscal constraints, will more probably limit the size of a simulation than will TSAR's structural design. That design permits up to 63 airbases with up to nine types of aircraft; other limits imposed by the TSAR code include five types of missions per aircraft type; 320 types of personnel; 100 types each of equipment, munitions, and TRAP; 3200 types of spare parts (LRUs and SRUs); 250 facilities per airbase (in addition to aircraft shelters); and 5000 aircraft maintenance tasks, 5000 parts repair procedures, and 5000 equipment repair procedures. These considerations are discussed more fully in the User's Manual.

TSAR provides users with an analytic structure within which a rich variety of potential improvements for theater airbases may be tested *in a common context*. New passive defenses, new maintenance doctrine, modified manning levels, increased stock levels for parts and equipment (etc.) as well as a variety of concepts for theater-wide resource management all can be examined with TSAR in a common context in terms of their ultimate effect on the system's capabilities for generating sorties. The simulation represents flight line aircraft maintenance tasks, parts and equipment repair jobs, munitions assembly, and civil engineering base recovery and reconstruction activities.

DISTINCTIONS AMONG SORTIE GENERATION MODELS

A considerable number of sortie generation models have been developed within the last few years by various organizations. All are useful for certain kinds of analyses of the sortie generation process but, because each had its own set of design objectives, there are many distinctions among their capabilities and limitations. Some of these models are quite aggregated and therefore fairly inexpensive to operate, and others can handle highly detailed aircraft representations.

It is impossible in a short space to describe all the similarities and differences among a broad range of complex simulations, but Table 1 provides a gross comparison of several contemporary sortie generation models. Some have been around for some years, and others are newer. The comparison is structured in terms of a set of capabilities that are important in assessing the response of the sortie generation process to air attack.

As the notes to Table 1 indicate, several of these models are structured in terms of a number of "channels" for processing on-equipment maintenance tasks, and a quantity of generic supplies; 10 to 20 channels are often defined to reflect different shops, or types of jobs.

Table 1

COMPARISON OF SORTIE GENERATION MODELS

Capabilities	(4) AIRBASE	(2) SAMSOM	(1) LCOM	(5) TURNER	(6) IABG	(7) FORSCAP	(8) TSAR TSARINA
Land-Fix-Load-Fuel-Launch	X	X	X	X	X	X	X
Resources Distinguished on Flight Line	C S	C	X	R	C S	X	X
Resources Distinguished in Backshops			X			S	X
Airbase Attacks	A				A		X
Optional Procedures, Cross Training							X
Multi-base: Mutual Support							X

Model (Ref.)

X — Simulated
C — Capacities expressed in terms of channels/shop
S — Consumables lumped (within shops)
A — Supplied by auxiliary calculations
R — Analytic expression derived from regression analyses of LCOM results

This approach was avoided in TSAR and TSARINA because of the judgment that the localized bottlenecks that could develop as a result of highly irregular damage among specialists, equipment, munitions, and spares could not be captured with an aggregated representation. For example, it was judged that one could not adequately represent the effect on sorties of damage to the ILM, unless the ILM process itself were simulated in considerable detail. And a multi-base model was essential if one were to represent the possibilities for mutual assistance that would be so eagerly sought in a crisis.

REPORT ORGANIZATION

TSAR documentation has been designed to permit four classes of potential readers to acquire an appropriate level of understanding without getting unnecessarily involved with extraneous details. The present report is intended for those who only wish to obtain a broad overview of TSAR and for those who desire a full understanding of the logic in the simulation but who wish to avoid programming details. The three-volume TSAR User's Manual [9-11] is intended for readers who will be concerned with preparing input materials and in operating TSAR and for those interested in modifying and extending the program logic.

The next two sections of this report should suffice for a broad overview of TSAR, while the remainder of the report explains in greater depth the logic that controls the various types of activities that are simulated. Section II introduces the reader to the scope of the TSAR

simulation using a series of illustrated descriptions that proceed step by step from the fundamentals through the various complications that may be introduced. Section III expands on the framework developed in Section II and introduces the reader to the sequence of activities that are represented in the simulation.

The remainder of the report presents a series of comprehensive discussions of TSAR's logic for each of the types of events simulated. To fully understand the simulation, one must understand what the events are, how decisions are made as to when they begin and when they end, and what resources are required for each event. Of particular importance are the internally generated events that must be defined, initiated, and concluded and that sometimes must wait or be interrupted. On-equipment aircraft maintenance tasks, off-equipment parts repair jobs, equipment repair jobs, munitions assembly jobs, and civil engineering reconstruction jobs generate such events.

Sections IV through XI treat most of TSAR's features and operating modes, and as a consequence often become quite involved. Nevertheless, several of the more specialized options that are available with TSAR have not been introduced in this preliminary volume in the interest of clarity; full descriptions of the user controlled options will be found with the instructions in Sec. XIX of Vol. II of the User's Manual.[10]

Despite the unavoidable complexities required to describe TSAR's many features, the reader should be aware that TSAR can function usefully in a wide variety of less complex modes when that is appropriate. A great many of the features can be dispensed with by the simple act of not entering the pertinent data. At its least complex, TSAR would function with one aircraft, one airbase, one mission, a flight duration, a turnaround time, and a single periodic sortie demand. No resource, other than the aircraft, would need to be identified.

DETAILED DESCRIPTIONS OF SIMULATION LOGIC

The remaining sections of this report are organized as follows:

Section IV provides a detailed discussion of aircraft maintenance activities. The different types of maintenance are described first, and then the reader is familiarized with TSAR's flexibility for representing the sequencing of these activities to prepare an aircraft for a subsequent flight after it has landed. Battle damage, deferred maintenance, cannibalization, substitute procedures, cross-trained personnel, and rear-area maintenance are each discussed.

Section V outlines the projections of aircraft availability and demand that are used to achieve a degree of efficiency in the utilization of the available resources. These projections provide a basis for decisions regarding aircraft assignment, prioritization of unscheduled maintenance, and munitions buildup.

Section VI first describes the steps taken in selecting a mission assignment for an aircraft and then outlines how aircraft reconfiguration and munitions loading tasks are represented. The basis for deciding which munitions are to be assembled and the manner in which these activities are managed concludes this section.

Section VII outlines TSAR's representation of parts repair and equipment repair jobs. It first describes how the user may elect to let TSAR define the initial spare parts at each base and the zero-time parts pipelines from CONUS to the bases. The activities simulated in carrying out on-base and off-base parts repair jobs are described next, along with a discussion of LRUs, SRUs, and NRTS actions. This section concludes with a description of the way

equipment breakdown and repair are simulated, including the more complex treatment required to capture the partial-mission-capable state for AIS test equipments.

Section VIII explains the many options the user has available for representing the expected wartime demand for sorties. Both alert forces and scheduled flights may be specified, and they may be differentiated by base, aircraft type, mission type and priority, and launch time. The sequence of steps taken in launching an aircraft are described, as are the special actions taken when a base has been closed to operations by runway damage.

Section IX describes how estimates of airbase damage as a result of enemy air attack can be generated using the companion TSARINA model, and how these damage estimates are integrated into the ongoing scenario at the time of the simulated attack in the TSAR model. This discussion describes in some detail how losses sustained by the various classes of resources are handled and how these losses affect the ongoing operations at the base. The provisions for representing base engineer recovery operations are also outlined.

Section X outlines how shipments from CONUS are handled and how a scheduled intratheater transportation system can be defined. The mechanisms for simulating delayed and imperfect status information for use by the theater resource manager are also described.

Section XI concludes the descriptions of TSAR logic with a discussion of the options offered for simulating theater-wide management of resources. Aircraft, personnel, and equipment, as well as serviceable and reparable spare parts may be transferred among airbases; this section defines the rules that govern such management actions.

Section XII introduces readers to the variety of output data that are available from TSAR simulations, to show them how TSAR might prove useful for their particular problems.

II. TSAR OVERVIEW

BASIC INTERACTIONS

Figure 1 suggests the basic interactions that are simulated. The recovery of an aircraft and its preparation for a subsequent combat mission involve tasks that depend upon various airbase resources. At its most basic, TSAR interrelates the sorties that are flown with the availability of 11 classes of resources. By specifying a set of demands for combat sorties one can measure a base's capability for meeting those demands. The user's representation of the on-equipment tasks required to ready an aircraft for flight, and of the resources that are involved, can be either aggregated or highly detailed, depending upon the issue to be addressed. The central boxes in Fig. 1 illustrate the kinds of activities that can be represented and the types of resources that can be specified as task requirements. Other model features are noted around the figure.

AIRCRAFT MAINTENANCE

Figure 2 illustrates how personnel and support equipment that are assigned to aircraft maintenance may be organized into independent sub-groups (such as the aircraft generation squadrons in COMO) that are distinct from those involved in intermediate level maintenance (parts repair), and how these ILM personnel may be organized into several different work centers, or shops. Furthermore, one may simulate the assembly of weapon components into munitions for aircraft loading. Aircraft losses in combat and the repair or salvage of battle-damaged aircraft can also be treated. When spare parts are required to ready an aircraft for flight and none are available, they may be removed from other aircraft (cannibalized) under certain circumstances. Spare parts that are NRTS are shipped to the repair point designated for that part.

AIRBASE DAMAGE AND RECOVERY

The dramatic scene depicted in Fig. 3 attempts to convey TSAR capabilities for simulating airbase damage and recovery. Based on damage assessments derived from the companion TSARINA model (or other damage assessment procedures), the TSAR model decrements the airbase resources and simulates flight operations with the surviving resources. While runways are closed, recovering aircraft are diverted to other bases and on-base aircraft are grounded. Sheltered aircraft may be destroyed, taxiways interdicted, and parts repair facilities damaged. Losses among personnel and WRM tend to restrict the effectiveness of flight operations. Replacements for personnel, equipment, spares, munitions, or aircraft lost in the air attack may be specified. Base engineering resources are assigned to priority repair tasks to reestablish flight operations.

When the resources required for various tasks are not available, TSAR can be used to assess the usefulness of various work-around, or make-do, procedures that the user stipu-

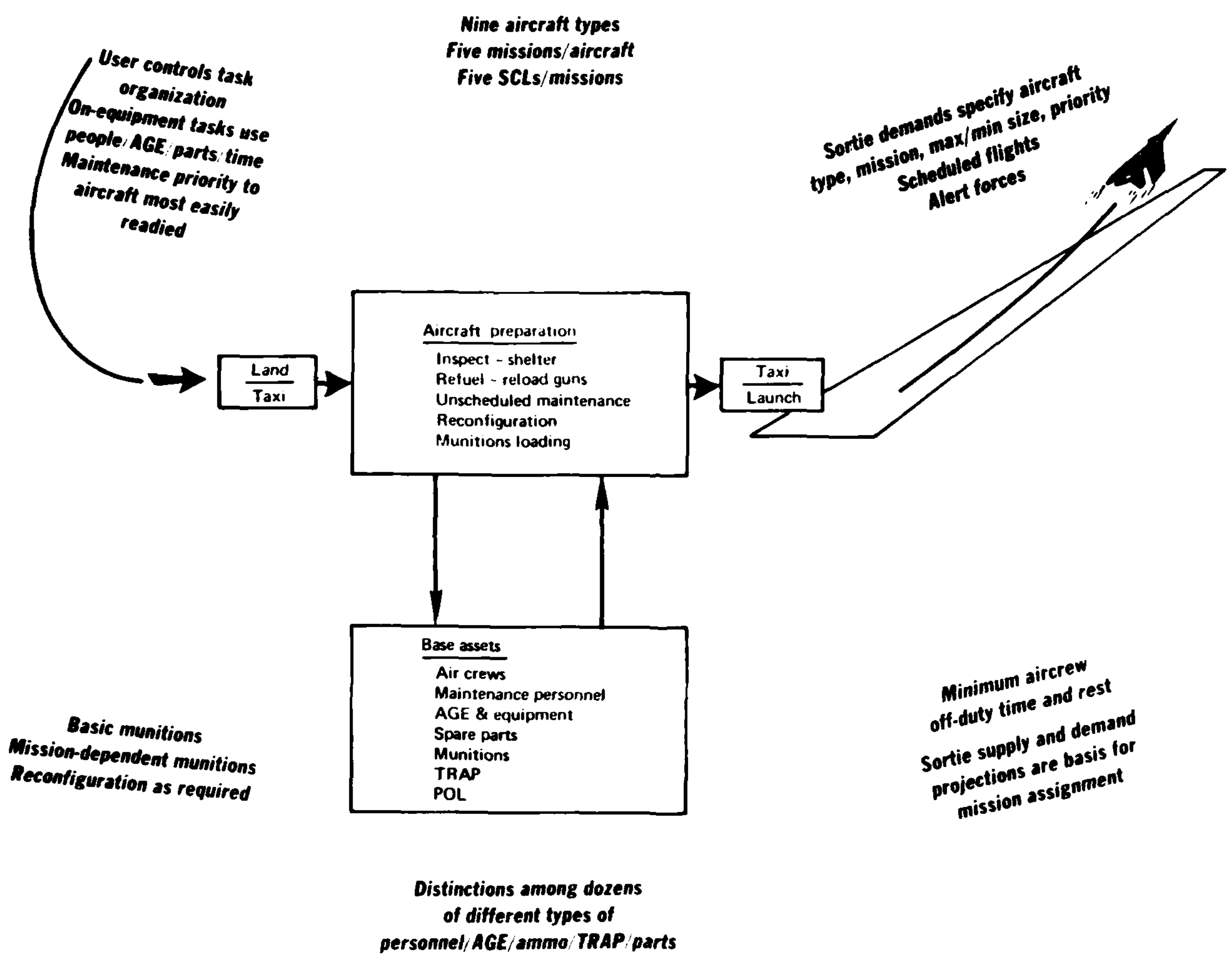


Fig. 1—Basic TSAR sortie generation features

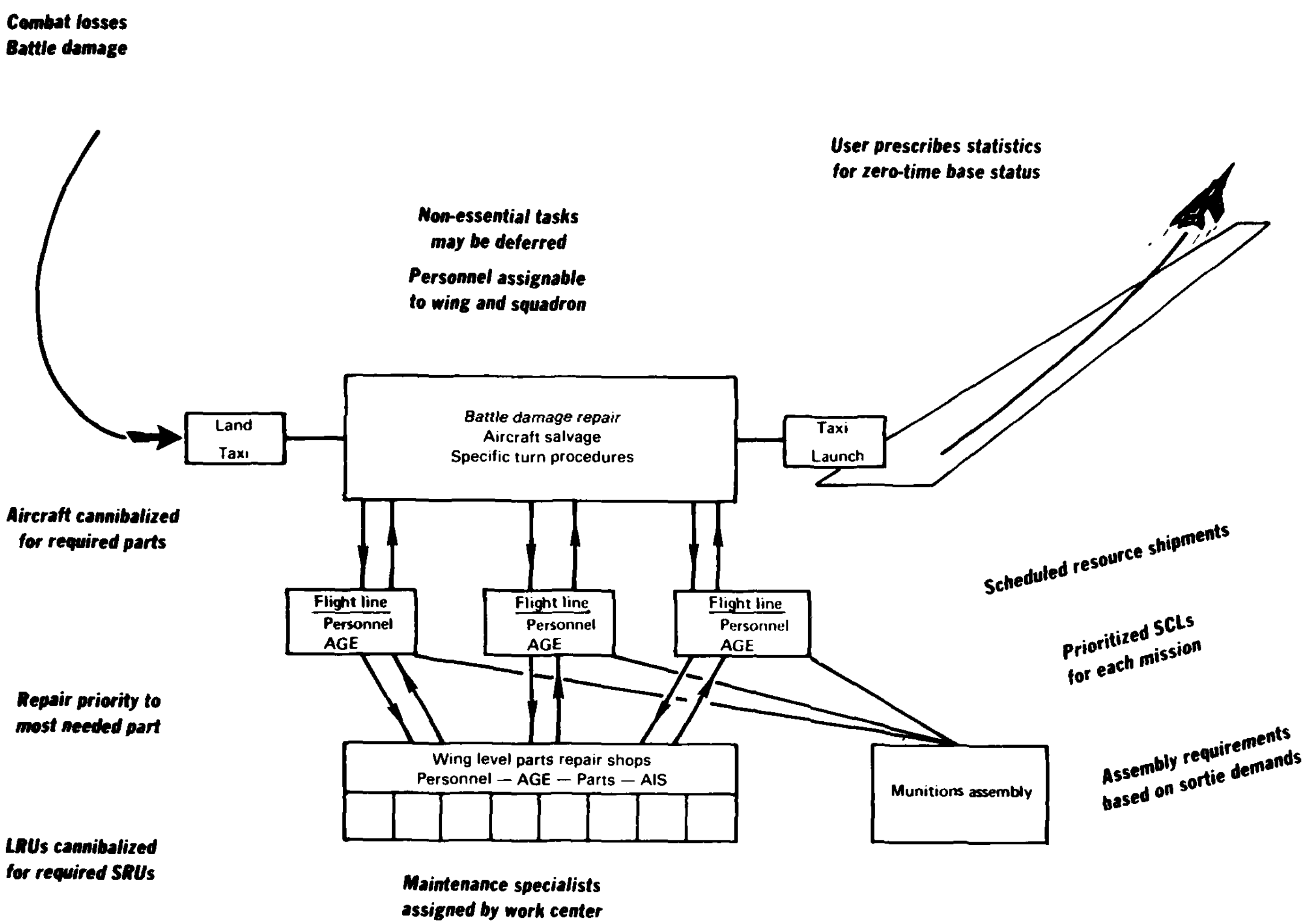


Fig. 2—Additional features of the TSAR simulation

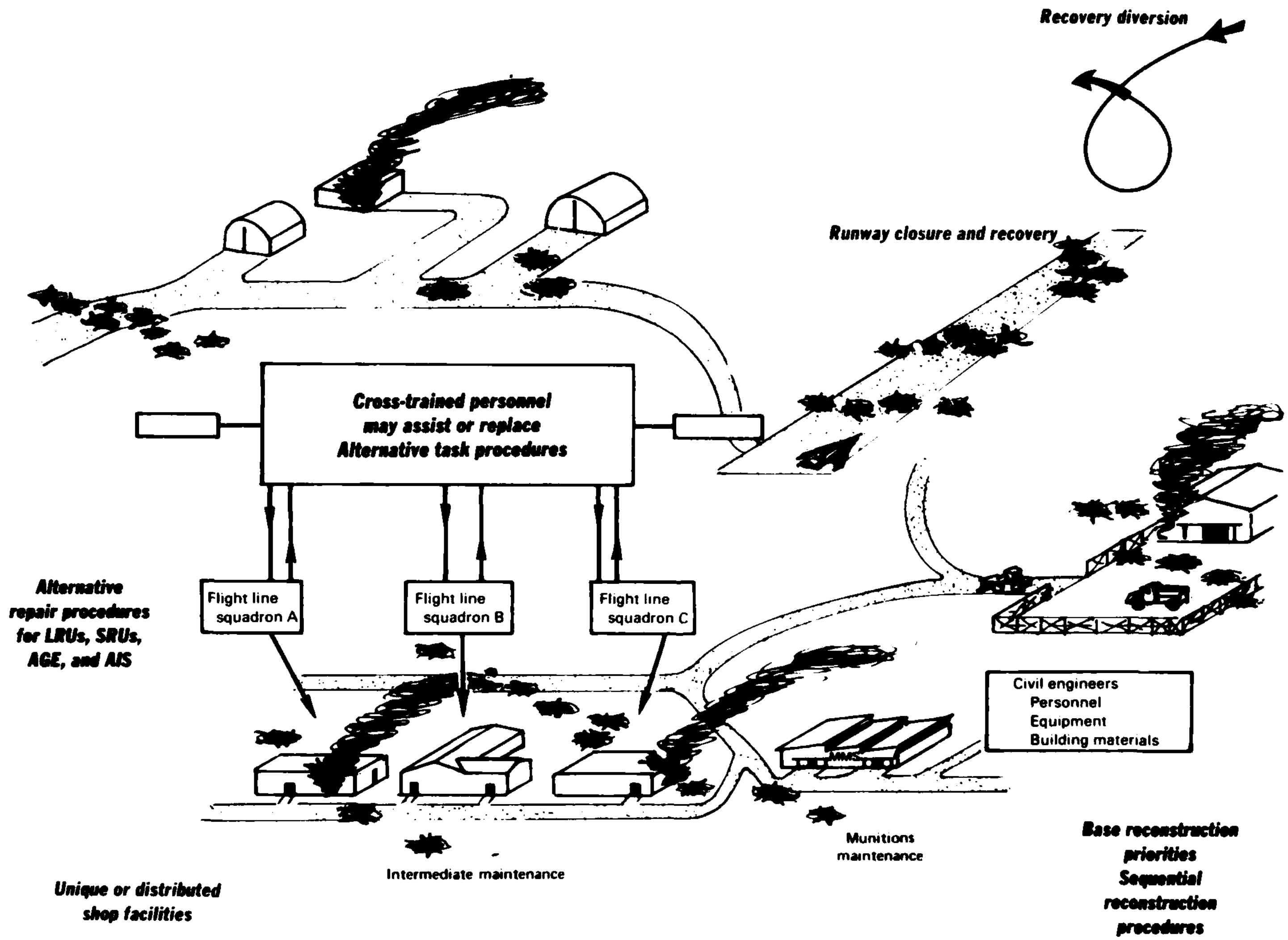


Fig. 3—TSAR simulation of air attack

lates. If certain personnel have been cross-trained to replace or assist other specialists on certain tasks, their contributions may be reflected.

THEATER-LEVEL FEATURES

Figure 4 shows some of TSAR's theater level features. Several airbases may be simulated simultaneously, each with its own aircraft and sortie demands. Airbase attacks may be scheduled uniquely against each base, and the damage sustained in each attack is unique. Each base is assigned its own complement of resources and each base may use its own maintenance procedures.

Aircraft Management

TSAR offers several options for managing aircraft resources. If the user designates a pool of "filler" aircraft, they may offset degradations due to lost and damaged aircraft, as well as aircraft with excessive maintenance requirements and those that have been withdrawn to a rear base for maintenance. These fillers may be used in addition to, or instead of, a reserve of aircraft in CONUS for replacing losses. TSAR options for managing the theater's aircraft resources are designed to simulate various decisions that theater managers would, in certain circumstances, attempt to make to enhance the sortie generation potential of their aircraft force. Included would be the replacement of lost aircraft, the insertion of reserve aircraft to offset aircraft immobilized by the need for extended maintenance, and various work-leveling decisions. Figure 5 illustrates many of TSAR's capabilities for managing aircraft resources.

Spares Management

Backshop capabilities also may vary from base to base. The bases may operate in isolation or with some degree of mutual interdependence, and they may be supported with a theater capability for centralized resource management, as suggested in Fig. 6. Parts may be transferred laterally for repair, and serviceable parts may be obtained by lateral resupply actions. When resources are managed centrally the quantities of personnel, equipment, and spare parts are checked periodically against the then projected demands, and these resources may be redistributed so as to offset imbalances. All aircraft spare parts entering the theater from CONUS may also be managed by the central authority.

Transportation

To support these operations the theater may have a scheduled intra-base transportation system; individual shipments may be delayed, cancelled, or lost en route. Base resources are reported periodically to the theater manager; transmission times are finite and the reports may be delayed, incomplete, or lost.

Centralized Intermediate Repair Facilities

Figure 7 introduces the final feature that may be simulated with the TSAR model; a centralized intermediate repair facility, or CIRF. This theater installation may be used to

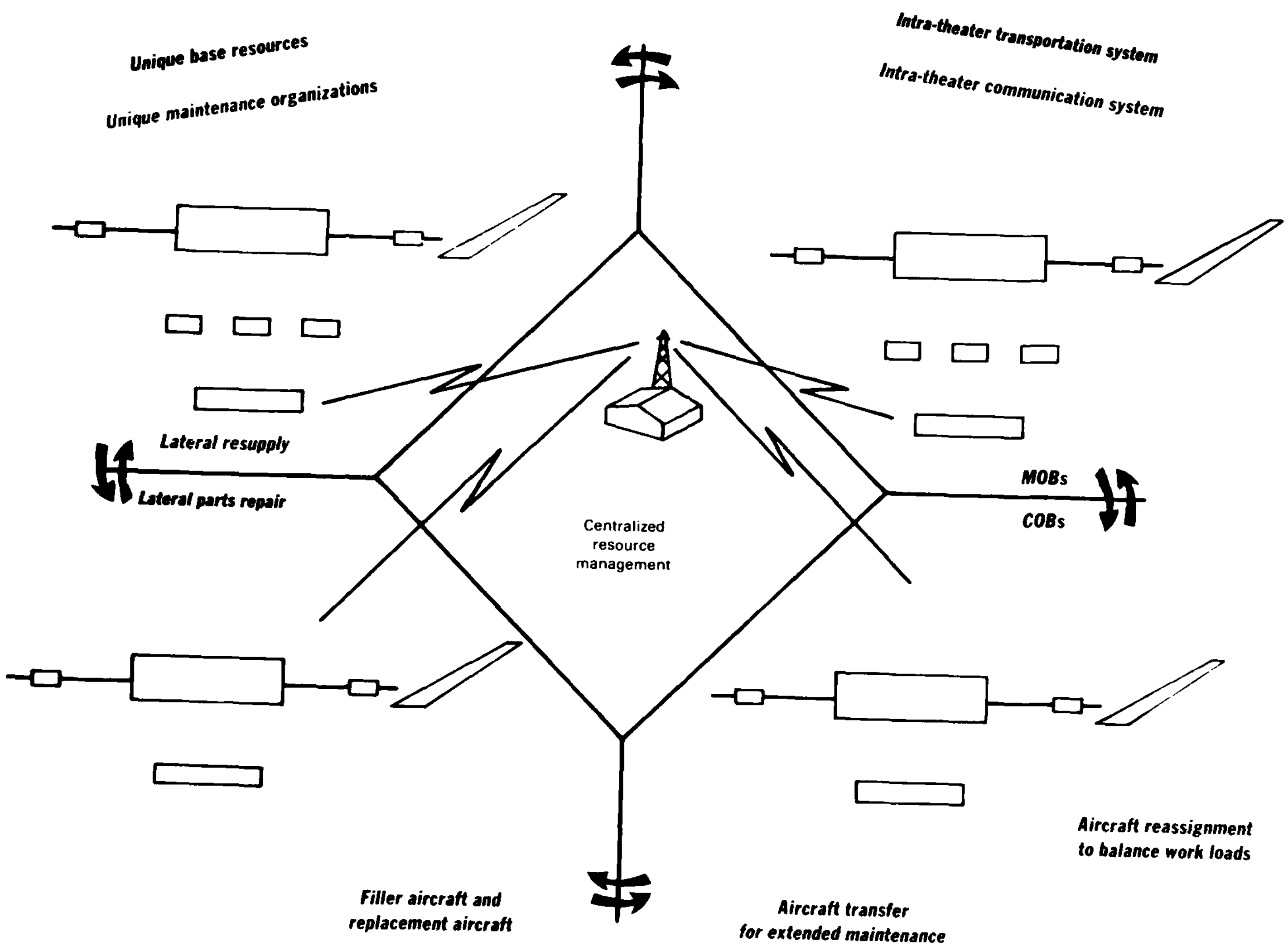


Fig. 4—Theater resource management and redistribution

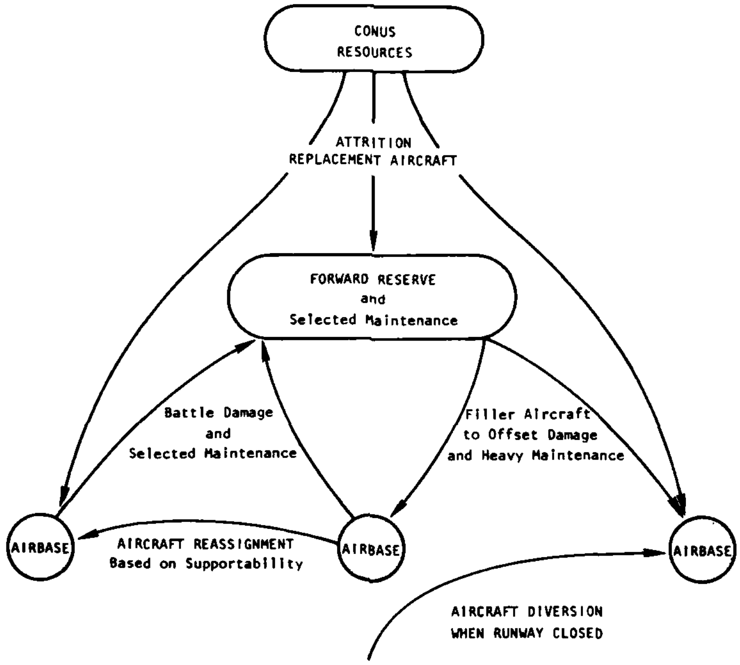


Fig. 5—Aircraft management options

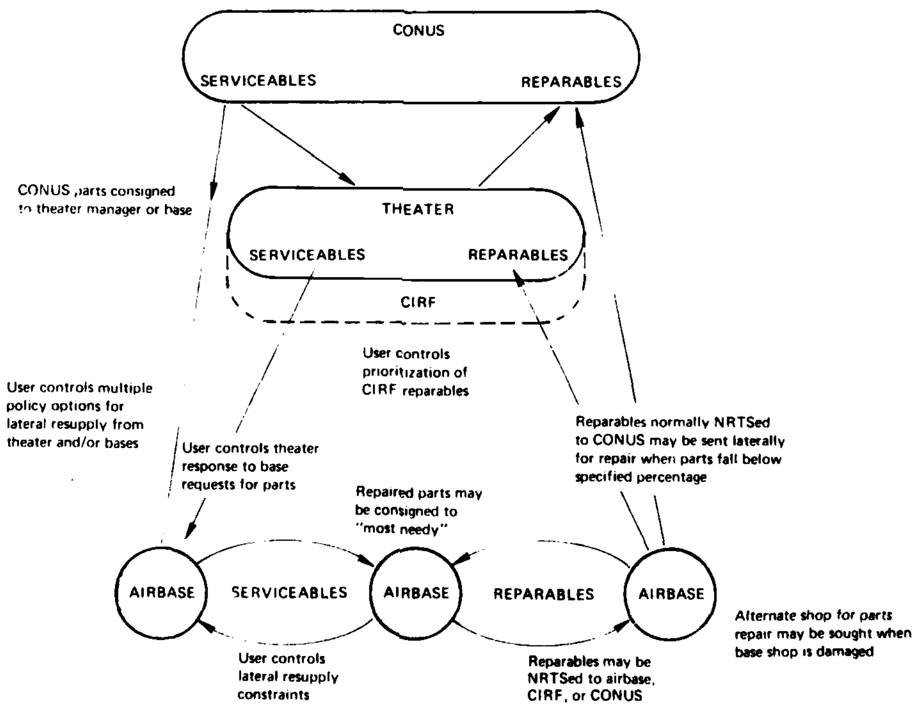


Fig. 6—Theater management options for spares

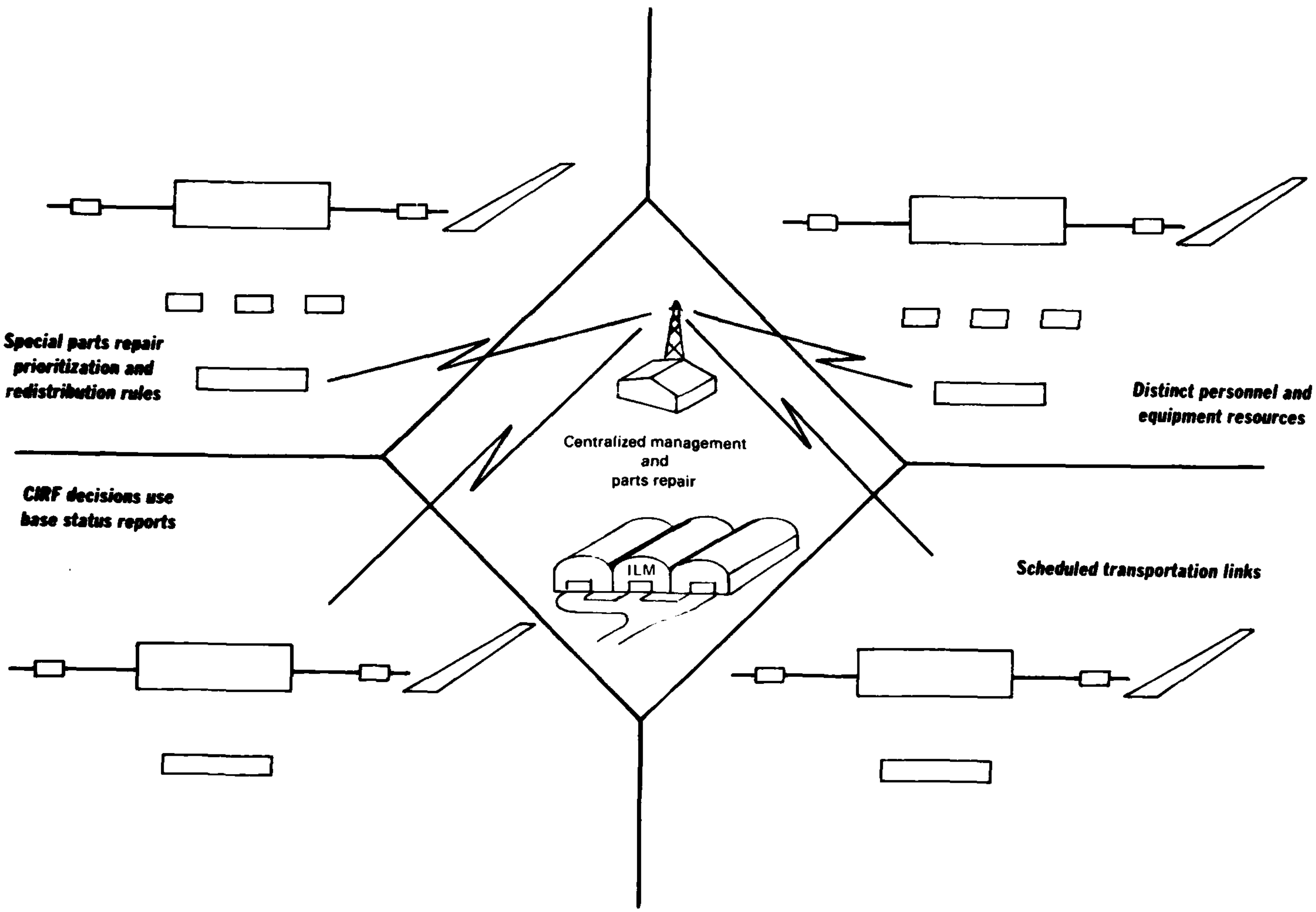


Fig. 7—Centralized intermediate level maintenance

repair specified types of aircraft spare parts. This facility operates in accordance with its own decision rules for prioritization of parts repair and for the distribution of repaired parts. The CIRF is interconnected with the various operating bases by unique links of the intratheater transportation system. And as with other theater installations it may be subjected to airbase attack.

III. ACTIVITIES MODELED IN TSAR

This section expands somewhat on the introductory description of Sec. II without getting involved in the details that are encountered in the thorough review provided in Secs. IV through XI.

AIRCRAFT OPERATIONS

In TSAR, specified numbers of aircraft of various types can be assigned to each airbase. The aircraft of a given type at any airbase may be supported by a common pool of resources (personnel and equipment), or, as in the COMO concept, the aircraft may be organized into two or three sub-groups (squadrons) each supported by its own set of resources. The initial status of these resources may reflect an assumption that there was sufficient warning time to work off all flight line and parts repair tasks before the simulation began, or it may reflect user-specified levels of flight line and parts repair activity. The aircraft are launched on sorties in response to a set of user-supplied sortie demands, differentiated by base, aircraft type, mission and priority; if a base is not specified, the sortie demands are allocated to the base best able to generate the necessary sorties. Flights may be scheduled or scrambled on demand using aircraft that have been placed on alert. *Weather conditions* may be specified that prohibit flying on specific days with particular types of aircraft at specific air bases.

When an aircraft is lost on a combat mission, TSAR may request a replacement, and it will be received after a stipulated delay. When aircraft that are not lost return, they may be damaged, they may still have munitions, and they may have several unscheduled maintenance task requirements. The basic input data that govern the probabilities with which unscheduled maintenance tasks (other than battle damage repairs) are demanded—the break-rates—may be a fixed rate per sortie or varied daily by shop and aircraft type as a function of achieved sortie rate, or other user specified adjustment.

When an airbase runway has been closed because of an airbase attack, aircraft scheduled to land are diverted to other bases, preferably to one that normally operates the same type of aircraft. If base sortie generation capabilities are assessed daily, the base best able to support the aircraft is selected for aircraft recovery. During the period that a runway remains closed, that airbase's sortie demands are allocated to functioning airbases with the appropriate type of aircraft, either in proportion to the aircraft available or, if base capabilities are assessed daily, in proportion to the sortie generation capabilities of the bases. When a runway has been reopened, that base's aircraft recover at their parent base on completion of their next combat sortie, if base sortie generation capabilities are not assessed or, if they are, when their parent base's sortie-generation capability per available aircraft is within a specified percentage of that at the temporary base.

TSAR selects the next assignment tentatively when each aircraft lands; that selection takes into account the known demand at that base for sorties, the projected capability of the aircraft at that base to meet those demands, which of that aircraft's unscheduled maintenance tasks would need to be accomplished for the different missions, and when that particular aircraft could probably be readied for the different missions. All tasks that are not essential for the tentative mission assignment may be deferred and the available resources

concentrated on those tasks that are required. Deferred tasks are worked off either after a user-specified number of sorties or at night and on those days when weather conditions prohibit flight. If aircraft are eventually found not to be needed for the mission for which they were readied, they are reassigned and reconfigured for a more appropriate mission.

AIRCRAFT MAINTENANCE

The user is given substantial flexibility in defining the rules by which aircraft maintenance tasks are processed. He may permit the activities of certain groups of shops to proceed simultaneously and may require that the activities of several such groups of shops proceed in a specified order. He also may separately control these prescriptions for simultaneous and sequential operations for each aircraft type at each base. Furthermore, for those groups of shops that are permitted to proceed simultaneously, certain exceptions may be specified in the form of lists of activities that are incompatible with each particular task. These features permit alternative maintenance operating doctrines to be simulated and to be examined for their influence on sortie generation capabilities. Work speed-up and other procedures to shorten on-equipment, preflight, and off-equipment activities also may be specified.

On-equipment maintenance tasks may require a number of each of two types of people, one or two pieces of specialized equipment, and a spare part; each task is either a single set of such requirements—a simple task—or a network of tasks, each with its own demand for personnel, equipment, and parts. When resources are limited, those aircraft most likely to be readied first (given sufficient resources) may be given priority.

If a required part is not available, (1) the broken one that is removed may be repaired on base, (2) the appropriate part may be removed from another aircraft, (3) a part may be obtained by lateral resupply from a specified subset of bases, or (4) the part may be ordered from a central source within the theater. When a part cannot be repaired on base (is NRTS) it may be sent to a neighboring base or to a centralized facility in the theater designated to perform intermediate maintenance—a CIRF. When parts cannot be repaired within the theater, a replacement may be requested from a depot in CONUS. Parts may either be a simple part that with some probability can be repaired on base, or an LRU that has a defective SRU. For simple parts, there may be one specific procedure required to repair it, or one selected at random from two or more types of repair procedures. For LRUs the resource requirements to diagnose and replace the faulty SRU are specified separately for each SRU. In addition, distinct procedures may be specified for the repair of the SRUs.

Each maintenance task, parts repair job, and equipment repair job is done by the personnel and equipment associated with a particular work center, or shop. The user may group the resources and tasks into up to 25 different "shops" exclusive of those associated with the scheduled preflight maintenance tasks. Since each shop may be assigned several different types of personnel and equipment, those engaged in on-equipment and off-equipment tasks may be the same or different depending upon how the user wishes to define the base's maintenance policies.

SCHEDULED PREFLIGHT TASKS

Scheduled preflight tasks are also associated with the shop structure. These tasks involve aircraft refueling and the loading of both basic defensive and mission-dependent muni-

tions. The likelihood that the basic munitions and the mission-dependent munitions are retained from the previous sortie can be specified independently for each type of mission and for both classes of munitions. After mission assignment, aircraft configuration is checked and, if necessary, the aircraft is reconfigured; this may involve one or two separate tasks, each of which may require TRAP, personnel, and equipment. The loading of the mission-dependent munitions also may involve one or two separate tasks, each with its distinct requirements.

When munitions assembly tasks are simulated, munitions demands are projected periodically to define which types of munitions need to be assembled. Such jobs may require both personnel and equipment, much like other tasks in TSAR. When munitions assembly is simulated, initial stocks of munitions, as well as munitions shipments, are distinguished as to whether the munitions are assembled or not.

WORK-AROUND FEATURES

Several features are included that permit the user to simulate various "work-around" procedures that can alleviate resource constraints. One such feature permits the user to specify alternative resource requirements for any unscheduled on-equipment task, parts repair job, equipment repair job, weapons assembly task, or civil engineering job; one might, for example, specify that a three-man crew could do a normal four-man job in 50 percent more time. Similarly, when TRAP or munitions shortages do not permit the normal, or preferred, munitions to be loaded for a mission, several alternative loadings may be specified. A third "work-around" feature permits the user to designate that certain types of personnel have been cross-trained and that they may either replace or assist certain other specialists. This personnel substitutability feature is operative only for specified bases, and on specified on-equipment tasks, off-equipment jobs, munitions assembly tasks, or civil engineering jobs.

AIRBASE DAMAGE AND RECOVERY

The effects of damage due to airbase attacks may be simulated. The user specifies the time and location of the attacks and the percentage damage suffered by the various resources on the basis of other calculations. (TSARINA—a customized modification of the AIDA (Airbase Damage Assessment) computer model [3]—generates and stores airbase damage data in the exact format required by TSAR.) When aircraft or facilities are destroyed, some portion of the personnel, equipment, and parts that are present at these locations may also be lost.

Aircraft are kept in aircraft shelters when sufficient shelters are available, but the aircraft may be partially exposed when certain shop operations are underway at the time of airbase attack; different loss rates are applied in each case. Furthermore, damage levels may be distinguished between shelters for alert aircraft and other shelters. Aircraft in excess of those that may be placed in shelters sustain another distinct loss rate. After TSAR has decremented the various resources to the extent implied by the damage data, the surviving personnel are reorganized into night and day shifts. Replacement resources (aircraft, pilots, personnel, equipment, parts, munitions, TRAP, and building materials) may be ordered from CONUS when losses are sustained. After a user-stipulated delay to roughly account for the disruptive effects of the attack, the maintenance personnel resume their activities, unless their facility is required and has been damaged.

After an airbase attack, civil engineering personnel, equipment, and building materials

may be allocated according to a priority system to repair or reconstruct the damaged facilities. Operation of those facilities is resumed when they once again are functional.

CENTRALIZED THEATER REPAIR FACILITIES

In addition to simulating a set of airbases, the user also may specify the existence of a centralized theater distribution center or repair facility at which some or all intermediate maintenance is conducted. The centralized distribution facility can receive spare parts from CONUS and either retain them until demanded by a base, or transship (some or all) to the base with the earliest projected requirement. Such a facility can also be used to direct the lateral shipment of parts and other resources from one base to another. The repair facility, sometimes referred to as a CIRF, has maintenance personnel, support equipment, and spare parts (LRUs and SRUs). Parts are shipped to and from the CIRF from the operating bases and are processed in the manner prescribed by the user's choice of which theater management rules are to govern these operations.

THEATER RESOURCE MANAGEMENT

The simplest rules for CIRF operation prescribe that faulty parts are repaired in the order in which they arrive and that they are returned to the sender. The user may also invoke a variety of more complex management algorithms, not only for selecting what to repair and how to dispose of parts when they have been repaired, but for reallocating personnel, equipment, and parts among the several operating bases. Parts repair priorities can be based on existing and projected demands and on the relative requirements for parts for the various missions. Shipment priorities are related to the current and projected demands, on-base reparables, and enroute serviceables. When central stocks are insufficient to meet a base's demand, another base can be directed to ship the required part, if both the requesting base and the donor base meet certain conditions with regard to the importance of the demand and the availability of stock.

Daily estimates can be prepared of each base's capabilities for generating different kinds of missions with different types of aircraft. These estimates provide the basis for various aircraft management decisions. One application is in selecting which base is to be assigned demands for sorties for which no base has been specified. These data can also be used to support assignment decisions when aircraft must be diverted and when they are transferred from base to base.

The theater-wide management of the various resources is supported by a user-specified scheduled transportation system that may be subjected to delays, cancellations, and losses. TSAR also permits the user to represent a theater-wide reporting system that can provide the central management authority with periodic resource status reports from the several operating bases; these reports may be delayed, incomplete, or lost.

When these transportation and communication systems are coupled with the sets of rules for distributing and redistributing resources among the operating bases, various concepts of theater resource management may be represented and examined in the context of realistic transportation and communication imperfections. In its current formulation TSAR already includes certain alternatives for the theater management rules and has been designed to readily permit additions or modifications.

IV. UNSCHEDULED AIRCRAFT MAINTENANCE

The primary constraints on the continuous recycling of aircraft in wartime are the requirements for adequate launching surfaces, the availability of aircrews, munitions, and fuel, and the necessary maintenance to permit the aircraft to fly militarily useful sorties. Of these constraints the last is clearly the most complicated since it involves complex interdependencies among a variety of resources. A basic reason for the level of detail in TSAR's formulation was to gain an understanding of the effect of high levels of sortie demand and battle damage on these complex processes that are needed to ready aircraft for combat and that depend on a variety of other actions and resources. This section first presents an overview of how aircraft maintenance is simulated and then describes various elements of the process in detail.

OVERVIEW

Aircraft maintenance activities can be divided into scheduled and unscheduled tasks. The scheduled requirements include (1) periodic maintenance, performed at specified intervals of flying time; (2) certain essential ground tasks; (3) the reloading of certain basic munitions that are carried for any type of mission; and (4) the preflight maintenance tasks (loading mission-dependent munitions and refueling) required prior to each flight. As currently designed, TSAR does not simulate periodic maintenance, because it is assumed that such maintenance would be postponed during the critical phases of conflict. TSAR does handle all other scheduled maintenance activities.

The other problems that develop and demand attention constitute unscheduled maintenance. Within TSAR, unscheduled maintenance tasks develop at random or are generated in battle; the former are categorized as required or deferrable, on a mission-by-mission basis. It may be specified that deferrable tasks be accomplished after some number of sorties, before the next day's flying, or postponed indefinitely until they are required for a new mission. For some tasks the aircraft may have to be ferried to a major support base, presumably located further to the rear.

The various specialized personnel, ground support equipment, spare parts, and facilities that constitute a base's maintenance capabilities can be represented in TSAR. The personnel and equipment may support all the aircraft from a common pool, or they may be organized into sub-groups that support sub-groups (squadrons) of aircraft and a wing-level organization that supports the several squadrons. User supplied information describes the various tasks that may be performed on an aircraft (on-equipment tasks), the personnel and equipment required to carry out the tasks, and the work-center (or shop) that is normally responsible for each task. The maintenance personnel, equipment, and parts that are required for each task are considered to be assigned to the appropriate shop.

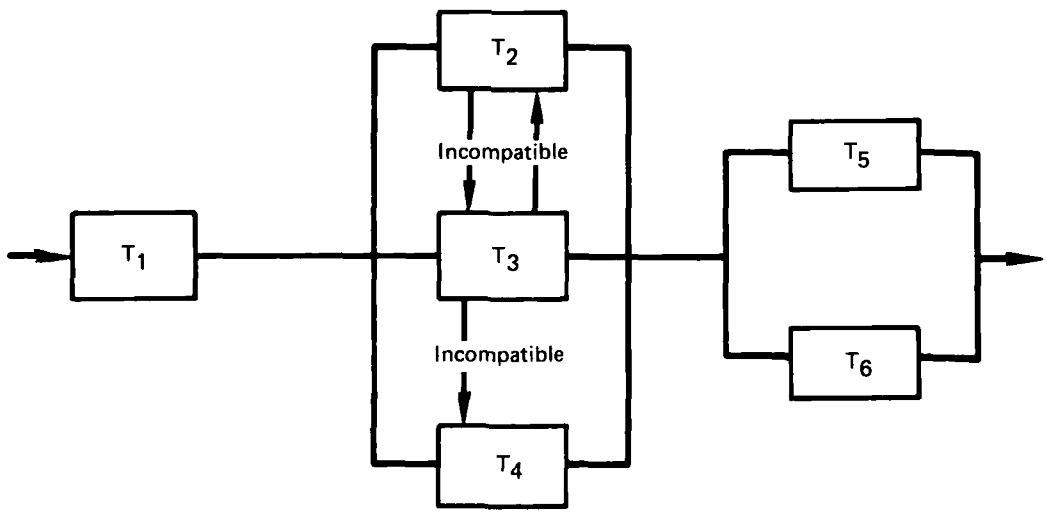
TSAR permits the user to define the requirements for each on-equipment maintenance task as either a one-step procedure, a multi-step network of sub-tasks, or a sequence of multi-step task networks. The requirements in the one-step procedure—a simple task—may include a number of each of two types of personnel, one or two pieces of support equipment, a part, an undamaged shop, and an amount of time (specified by a mean and distribution if desired).

More complex tasks that involve differing groups of personnel, equipment, and parts are represented by a network of tasks, or a sequence of task networks.

The user may specify alternative sets of resources for any of the elements of a task, and these alternatives will be considered whenever insufficient resources are available to accomplish the task with the normal procedures. If the alternative resources are available, the task is done without reference to the subsequent availability of the normal resources. There may be as many alternative sets of personnel, equipment, and time specified for each task element as the user's knowledge and available data permit. The user may also simulate the situation in which certain specialists at specified bases have received cross-training so as to be able to assist or replace another specialist on a specified sub-set of the latter's normal activities. Cross-trained personnel are assumed to perform the tasks for which they are qualified in the same time as the specialists who normally perform those tasks.

TASK ORGANIZATION

The user fully controls the organization and sequencing of the various tasks that are required on each aircraft for each aircraft type and for each aircraft base. Some tasks may be pursued simultaneously, some may have to be done in a specified order, and others may occur in any order, but not at the same time. Battle damage must be repaired either simultaneously with or prior to starting the first of any other tasks. These options can be illustrated as follows:

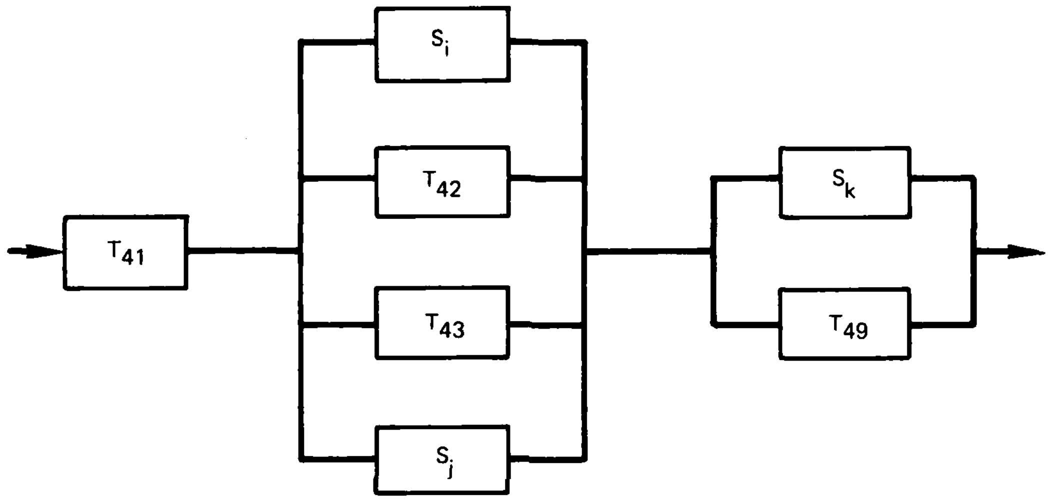


In this instance, Task T_1 is accomplished first; Tasks T_2, T_3, and T_4 are done next, as available resources permit, except that tasks T_2 and T_3 may not be done simultaneously, and Task T_4 must be done before Task T_3. Then, when these tasks are completed, tasks T_5 and T_6 may be begun; the aircraft may be launched when they are completed. If the aircraft had received battle damage, it would be repaired before, or at the same time as, Task T_1.

Any of the tasks in the preceding illustration may involve spare parts, may actually be a network of several sub-tasks, and may occur only with a specified probability. Furthermore,

the sequencing of the various tasks may be defined differently for each aircraft type and for each airbase.

For convenience, the majority of the unscheduled on-equipment aircraft tasks will normally be grouped together with the other tasks performed by the same work center or shop. With this procedure, on-equipment aircraft maintenance tasks are specified in the following manner:



where S_i, S_j, and S_k are the collections of on-equipment tasks accomplished by the specialists from shops i, j, and k.

The personnel, equipment, parts, and required time are specified separately for each task, and for each segment of a task network. If special damage repair personnel (RAM—rapid area maintenance—teams) are to be used for the repair of battle damaged aircraft, one can impose that requirement simply by identifying such personnel as a unique type.

TSAR provides for a total of 30 shops. All aircraft maintenance personnel, equipment, and parts "belong" to one or another of these shops; lists of the tasks and repairs that are underway, interrupted, and waiting are maintained separately for each shop. The first 24 shops are intended to be used for groupings of unscheduled maintenance tasks that are performed by the specialists associated with each of the several maintenance work centers. If desired, the personnel of each shop may be assigned to one, two, or three aircraft squadrons, and to a wing-level organization for repairing parts and equipment, as in the COMO maintenance concept. Shops 27, 28, and 29 are used with the pre-flight tasks (reconfiguration, munitions loading, and refueling) as outlined in Sec. VI, and Shop 30 is reserved for munitions assembly activities. Shop 25, the "flight line" shop, is intended to be associated with tasks other than the preflight tasks that are performed after all, or most, sorties and that may also involve munitions and TRAP resources.

Sample Maintenance Cycle

The various features for representing the organization and processing of aircraft maintenance tasks will permit the user to rapidly define and test a wide variety of different base

maintenance cycles from landing to takeoff. An example of a cycle that might be defined is shown in Fig. 8.

The user may specify a finite postflight delay to account for taxiing etc. immediately after landing. This is also when TSAR determines which tasks are required, tentatively, what mission the aircraft is to be prepared for, and which required tasks may be deferred for the next mission. If the aircraft has suffered battle damage, those repair tasks are scheduled either before any other on-equipment work or with the first set of required tasks. In the example, the user has specified that ordnance that had not separated from the aircraft when released must be removed (Task 45) after 4 percent of the sorties. When that is completed, any unscheduled maintenance that is required by Shops 1, 17, 19, 2, 4, 9, and 24 may be initiated. Two scheduled tasks are also specified: the requirement to reload guns (Task 62) is controlled by the expected munitions retention entry for basic munitions; the requirement to hang fuel tanks, Task 47, is specified, in this example, as being needed after 80 percent of the sorties; neither of these tasks is mission dependent. These tasks that are different in character from most others in that some of the resources are consumed must be assigned to Shop 25.

When all of the first set of possible tasks have been completed, shop activity by Shops 8, 3, 21, and 12 may be begun, along with Task 51. And when those jobs have been completed the preflight preparations may begin. These preparations, discussed at length in Sec. VI, involve a possible delay (at which point a final mission determination is made), aircraft reconfiguration (as required), mission-dependent munitions upload, and refueling. As indicated, the delay, reconfiguration, and uploading always occur in sequence and are specified as Shop 26. Task 52 is also indicated as being accomplished concurrently with the preflight preparations.

To specify that this task sequence is to be followed, the user would simply enter the following string of numbers: 45, 0, 62, 47, 1, 17, 19, 2, 4, 9, 24, 0, 8, 51, 3, 21, 12, 0, 26, 52, 29, 0, 0; the zeros separate the groups of activities that may be carried out simultaneously. A different string may be entered for each type of aircraft and for each airbase. Wherever any of the required maintenance tasks is one that must be accomplished at rear base, or if the user wishes to specify that particularly lengthy task sequences be done in the rear, the user-specified task sequence is replaced by three sequential sets of maintenance tasks. The first set, to be accomplished at the operating base, includes refueling and all tasks that are necessary to enable the aircraft to be ferried. The second set includes refueling at the rear base, all tasks that must be accomplished at the rear base, and other of the aircraft's required and deferred tasks as are implied by the user's setting of the relevant control variable. The third task set, those that are to be accomplished when the aircraft returns to the operating base, includes all remaining tasks that are required.

The requirements for on-equipment aircraft tasks are treated as independent with only two exceptions. First, for each aircraft type, the user may specify two different types of support equipment for which multiple demands can be satisfied with a single item; the auxiliary power cart and the hydraulic mule might be treated in this manner. Second, the user may prohibit more than one munitions load crew from being assigned to the same aircraft; this feature is invoked when the user specifies on the appropriate input card the type and number of personnel that compose a load crew.

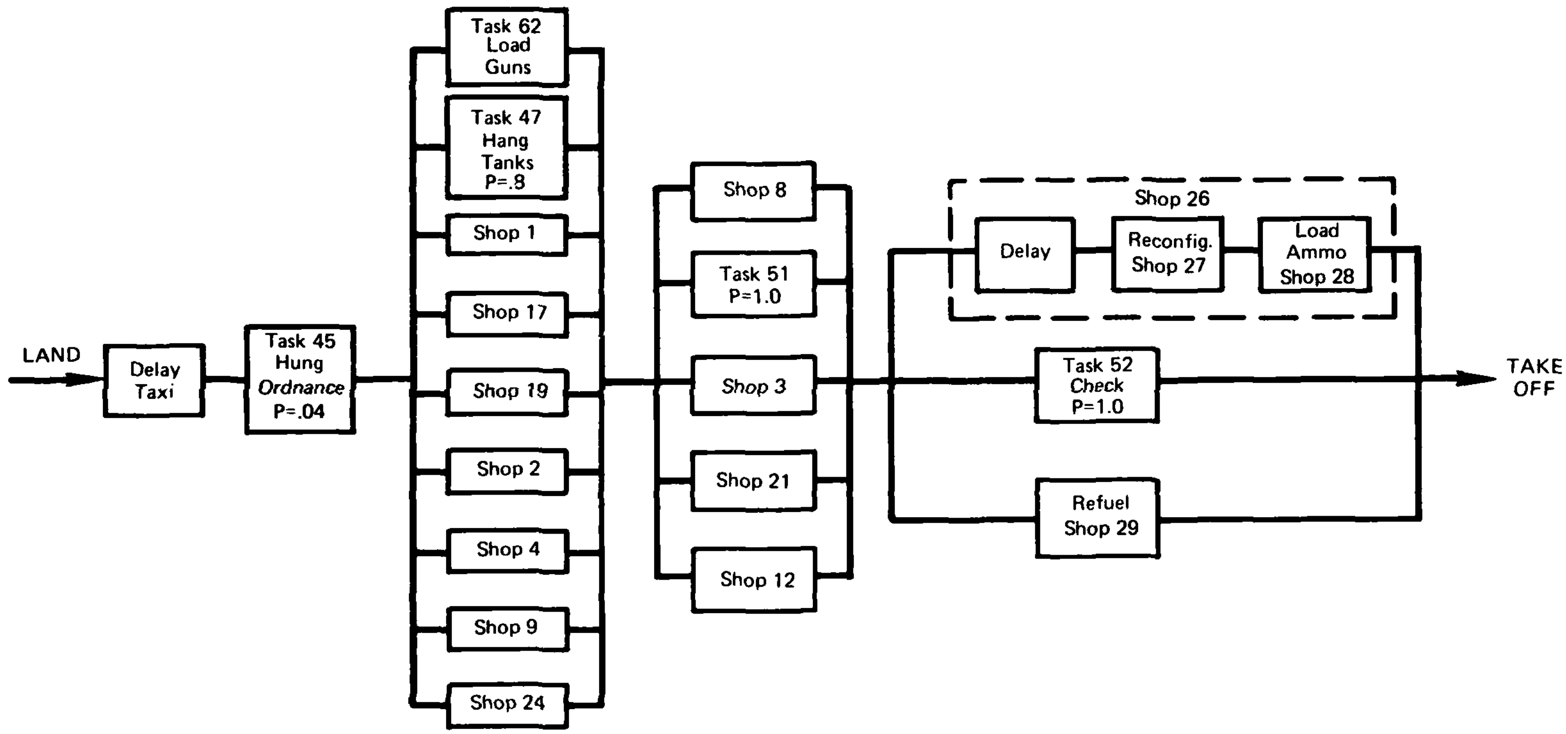


Fig. 8—Structural representation of on-equipment maintenance

DETERMINATION OF UNSCHEDULED MAINTENANCE REQUIREMENTS

The basic functions performed when an aircraft lands are (1) to initiate any user-defined postflight delay (to account for taxiing, inspection, etc.); (2) to identify what battle damage repairs are necessary; (3) to determine if any deferred tasks must be done at this time; (4) to identify newly required unscheduled maintenance requirements; (5) to determine whether any of the required maintenance must be accomplished at a rear base and, if so, to schedule aircraft refueling and transfer; and (6) to establish a tentative mission assignment for the aircraft and to categorize the newly defined tasks as essential or deferrable for that mission.

The first major logical steps after an aircraft lands are to establish which of the individual tasks and which of the collections of unscheduled tasks are required and what the expected time is for carrying out the essential maintenance. When an aircraft has received battle damage, those required tasks are determined first and are scheduled for repair before other maintenance is done on the aircraft. The times at which the aircraft would be expected to be ready to fly are estimated for each type of mission. These time estimates take into account the user's specifications as to which shops may perform on-equipment tasks simultaneously and which groups of shops must follow other groups. They also take into account only those tasks that may not be deferred for each particular mission. When the estimates are made in this manner, the nominal times when the aircraft could be readied for the various missions will typically differ for the different missions, and these times will also include at least a rough accounting of the queues, parts shortages, or facility damage that might interfere with the preparations for one mission, but not another.

Unless an aircraft is scheduled to be ferried to the rear for maintenance, the next step is to determine the highest priority mission that has insufficient aircraft to meet the known demand between the time the aircraft could be ready for a mission and the time horizon for planning. If no mission has such a deficiency, or if the deficient priority level is the same and occurs no earlier than for the aircraft's previous mission, the aircraft is committed to the same type of mission that it just completed. Otherwise it is tentatively committed to that mission with the earliest and highest deficient priority.

Aircraft may be sent to a rear-area maintenance base either when specially designated tasks must be accomplished or when the estimated completion time for the required maintenance exceeds a user specified time. Both regular unscheduled maintenance tasks and battle-damage tasks may be specially designated as requiring action at a rear maintenance base; these task designations may apply to all aircraft, or only to aircraft at a COB. If the user has specified a maximum time for maintenance at forward operating bases, and the estimated maintenance time exceeds that value, TSAR checks that the time for that part of the maintenance that will remain when the aircraft reaches the rear will take at least as long as what must be done to prepare the aircraft for a ferry flight. If this test is satisfied the aircraft will be transferred after it has been readied to be ferried.

AIRCRAFT MAINTENANCE MANAGEMENT

After TSAR has tentatively selected an aircraft's next mission and the various scheduled and unscheduled tasks have been defined, TSAR attempts to initiate the required work on each of the first set of required tasks. When an aircraft has sustained damage in battle those tasks are scheduled first. If the required resources and parts are available to initiate a task

(using either the normal procedure or whatever alternative procedures the user has specified), they are withdrawn from stock, the actual task completion time is determined from the specified time distribution, and a record of the task and its resources is stored. If resources are not available the task is placed in the waiting queue of the appropriate shop. Tasks are ordered in the wait queue for each shop either on a first-in first-out (FIFO) basis, or to give priority to the aircraft that could be readied for flight first; the user specifies which logic is to be used.

Whenever an on-equipment task has been completed, TSAR checks to see if the released resources can be applied to an interrupted task or one that is waiting. If the completed task was an unscheduled maintenance task it then checks to see if the task is an element of a task network and, if it is, looks for the resources to start any subsequent task or set of parallel tasks. TSAR then sees if other tasks have been forced to await the just completed task because of an incompatibility; any such tasks are initiated, if resources permit.

If no tasks are in process or waiting for the aircraft, but one or more subsequent sets of required tasks remain, TSAR computes a new estimate of the ready-to-fly time, and initiates the next set of required tasks as resources permit. If no tasks are in process or are waiting, and no further tasks are required, TSAR checks to see if conditions permit deferred maintenance at this time; operations in this circumstance are discussed in a subsequent subsection.

One other key feature of the management operation permits the preflight tasks to be deferred in certain circumstances, so that the final decisions regarding mission assignment and munitions may be delayed until further information has been received regarding sortie demand. When these conditions (as discussed in Sec. X) have been met, the mission assignment and weapons loading tasks are allowed to wait while the other tasks are processed in accordance with the specified shop-task structure. When all required tasks are complete, deferred tasks will be initiated if TSAR estimates that they can be completed before the user-specified last allowable hour for commencing the weapons loading procedures.

ON-EQUIPMENT TASK INITIATION

When TSAR attempts to initiate an on-equipment task it performs the following checks. If a part is required, base stocks are checked to see if one is available. Then the task is checked to see if it must be delayed because work in process is incompatible. The program next checks for the availability of any facility that may be required and for the personnel and equipment specified for the task. If the user has specified that only one item of the required type of support equipment is needed for several tasks and one is already assigned to the aircraft, the additional requirement is ignored; also, if only one munitions load crew may be assigned to an aircraft and one is already at work, the task is delayed. If the aircraft is assigned to a squadron that has its own personnel and equipment, the required resources are sought from the appropriate group. If the facility is needed and is unavailable, or if insufficient support equipment is available, the shortage is noted and the program transfers to check any alternative procedures that the user may have stipulated for this task.

If insufficient personnel are available, but on-base personnel have received cross-training, TSAR checks to see whether such personnel can be used on this task and, if so, whether sufficient cross-trained or task-assist-qualified personnel are available. If they are not available, but the required number of specified personnel are involved in parts repair activities, those repairs are interrupted to acquire the personnel needed for the on-equipment task, when the needed part is in stock. If the required maintenance personnel cannot be obtained

by these procedures, the last option is to stop maintenance on another aircraft. This will be done only if the ongoing task has at least two hours remaining until completion and if the aircraft has a projected ready-to-fly time at least four hours later than the aircraft for which the personnel are sought. If there are sufficient personnel available but a needed part is not available, TSAR checks to see if it may be obtained from another aircraft by cannibalization (the various options that exist for cannibalization will be discussed in a subsequent subsection). If a part is not located, the fact that the aircraft has a "hole" is noted; if the user prescribed rules permit (see Sec. XI), an attempt is made to locate the needed part at another location in the theater and to have it shipped.

If all resources are available the task is initiated. The duration of the job is determined on the basis of the mean task time and the distribution specified by the user.

If a part is available but some other resource deficiency prevents the task from being initiated, any alternative procedure (set of resources) for accomplishing the task that the user has supplied is checked to see if those resources are available. If they are, the task is initiated with the alternative procedure; if they are not, the task must wait. When the task is placed in a shop's wait queue it is placed last in line unless the user has specified that the aircraft with the least remaining time before it would be ready to fly should be placed first.

The last step for a task that is being checked for the first time is to dispose of any part that must be removed from the aircraft. Unless the on-base shop that normally is responsible for the part has been closed by air base attack, the part is set aside to be examined on base and repaired when possible. If the shop is closed, the part is shipped to whatever location has been specified for lateral repair; if none has been specified the part is held on base. These procedures are discussed in Sec. VII. The part is removed and disposed of when the task is first checked, even though the resources are not available to start the on-equipment task at that time; it is assumed that the overall resource demand for the task is adequately approximated by the task's resource requirements whether they are used then or later.

CANNIBALIZATION

When a part must be replaced on an aircraft and a replacement is not immediately available, TSAR may be directed to cannibalize another aircraft for the part in certain circumstances.[1] The user manages the rules governing cannibalization by setting the appropriate control variables. The basic user choices are (1) whether an aircraft may be cannibalized for a part when there are reparables on base and, if so, (2) which of the aircraft may be considered. The aircraft that may be considered must be of the same type and must also be undergoing unscheduled maintenance. Four possible categories are defined: (1) an aircraft with parts missing, whose criticality for its designated mission would not be affected; (2) all aircraft that have parts missing; (3) an aircraft without "holes," if the needed part would not affect its designated mission; and (4) all other aircraft. If cannibalization is restricted to either of the first two categories, the donor aircraft must have at least as many missing parts ("holes") as the recipient aircraft. No matter which category is chosen, all aircraft in the first of these four categories are checked before the others. The user may also prohibit cannibalization of any aircraft whose estimated ready-to-fly time is within a specified time; for aircraft without "holes" TSAR has a built-in minimum constraint of 90 minutes for this time. A maximum number of "holes" on any aircraft may also be specified.

[1]Cannibalization may be prohibited for selected types of parts.

When one aircraft is cannibalized for a part to permit work to be carried out on another aircraft, the time required to get the part and to complete the basic task on the receiving aircraft is the sum of the time normally required for that task, plus either the user-specified time for cannibalizing for that specific part or the default cannibalization time; the default value for the latter time is one-half the true time selected for the task plus a fixed delay, as defined by the user.

ACCOMPLISHING DEFERRED MAINTENANCE

On-equipment aircraft maintenance that has been deferred as nonessential for an aircraft's designated mission may be taken care of in four different ways. The first possibility is that a different mission will be chosen for the aircraft for a subsequent flight and the deferred task will become mission essential and be initiated as a normal part of the preparation for that mission.

The second possibility is that a deferred task may be deferrable only for a certain number of sorties or until the end of the nominal flying day. In the first instance the task will be redefined as a required task after the designated number of sorties, and in the other it will be redefined after the end of the flying day.

Another possibility occurs in the evenings and at night when other unscheduled maintenance is completed; the deferred tasks on each aircraft are checked and those the user has specified must be cleaned up at night are converted to required tasks. An attempt is also made to initiate any other deferred maintenance. Other attempts are made at 2200 and 2400. A deferred task is initiated if the required resources are available and if the nominal time for the task will permit it to be completed no later than the hour specified by the user as the last time when the rearming process must begin.

The fourth possibility for working off deferred maintenance tasks occurs on days when the user has specified that the weather will not permit operations at a particular base for specified aircraft types. When this happens each base and each aircraft type is checked at four hour intervals starting at 0400, when it is presumed that that day's weather conditions would become known. For all aircraft that are otherwise ready to fly, the deferred tasks are started if resources are available and the tasks can be completed before the time the user has specified as the last hour for loading munitions on the following day.

V. AIRCRAFT STATUS PROJECTION

A simulation of airbase operations should emulate, at least in a limited way, the scheduling and control activities that are carried out by the job-control shop at each airbase to utilize available resources efficiently. Choices must be made as to the tasks to be performed, repairs to be done, munitions to be assembled, and aircraft assignments. In the real world these choices are made in the context of a much richer body of knowledge regarding assets, capabilities, and requirements than is possible (or at least practical) in a simulation. Furthermore, the procedures used and results obtained in the real situation are, at least in part, dependent upon the skill, knowledge, and experience of the job control managers available and therefore vary from one circumstance to another. All that can reasonably be expected of a simulation are mechanisms that allow the user to define broadly differing policies for managing aircraft maintenance and parts repair and to achieve a degree of efficiency in the use of the available resources.

A key TSAR feature is the periodic development of what might best be called the projection of aircraft supply and demand, which provides the data base, or context, within which decisions are made regarding aircraft assignments, unscheduled maintenance, and munitions buildup for the subsequent two-hour period.

As outlined at greater length in Sec. VIII in this report and in Sec. XIX of the User's Manual, the sortie demand data specify the airbase, the aircraft type, the mission, the number of aircraft, the mission priority, the FRAG receipt time, and the desired launch time. Provisions are included permitting the user to stipulate that a number of aircraft of a particular type be maintained in an alert (cocked) status so that they may be launched whenever they are needed for a specific mission. These data provide the information with which the pattern of sortie demands is projected.

Since the current status of each aircraft assigned to a base is known at any particular time, one may also make a projection of when sorties of various types might be launched. These projections are also made every two hours for each base, aircraft type, and mission for each of the several priority levels. Comparison of these projections of sortie demand and supply permits aircraft assignments to be made so as to give priority to the more urgent demands.

VI. PREFLIGHT TASKS AND MUNITIONS BUILDUP

The preflight events dealt with by TSAR include a preflight delay, final mission assignment, aircraft reconfiguration, loading of mission-dependent munitions, and refueling. Additional munitions—the basic munitions that are always to be carried—will normally be entered separately as individual tasks, as explained in Sec. IV. The other tasks to be discussed in this section in connection with the preflight tasks are the munitions buildup tasks. The procedure and resources associated with these two sets of events are sufficiently different from those for unscheduled maintenance that they require several special subroutines.

Before the discussion of the various rules that govern these events in TSAR, some definitions and conventions should be outlined. The preflight delay is seen as a period of dead time that the user might wish to specify before the mission-dependent munitions-related events and (typically) after the completion of the unscheduled maintenance tasks. When it is necessary to delay the preflight events until after the expected receipt of sortie demand information (as discussed in Sec. IV), the length of this delay is modified endogenously. Immediately following this delay, however defined, a final determination is made as to the next mission that the aircraft will fly and a tentative assignment is made to a specific flight, alert force, or set of spare aircraft. These selections are made on the basis of the most recent projections of aircraft supply and sortie demand and may involve a change of mission from that designated tentatively at the time of postflight "inspection." After TSAR determines what aircraft configuration is required for the most effective *available munitions for the next mission*, the aircraft is reconfigured as necessary, and the weapons are loaded if they were not retained from the previous sortie.

The periodic projections of aircraft supply and sortie demand are also used to generate the demands for munitions buildup. The munitions demands imposed by the sorties that are expected to be flown are compared with the available and in-process munitions, and work is initiated to offset any apparent shortfall. The prescribed procedures give priority to the earliest high-priority sorties that have been demanded.

Several TSAR work centers or shops are set aside exclusively for storing data related to these preflight events and to munitions assembly. Shop 26 is associated with the preflight delay and assignment, Shop 27 with reconfiguration, Shop 28 with mission-dependent munitions loading, and Shop 29 with refueling. Shop 30 is responsible for all munitions buildup tasks. As discussed in Sec. IV, the "flight-line" shop, Shop 25, is used in connection with the basic munitions and with certain TRAP, such as auxiliary fuel tanks.

MISSION ASSIGNMENT

After the preflight delay, if any, TSAR makes a final determination of the aircraft's *mission assignment* by checking the requirements for the aircraft's designated mission, first for alert aircraft and then for scheduled flights, from the highest priority level to the lowest permissible level as defined by the look-ahead planning process described in Sec. V. The aircraft is assigned to the highest unfilled priority demand.

If the aircraft is not assigned by this procedure to the mission for which it has been designated, TSAR checks to see which other missions the aircraft could be readied for, taking

into account whatever maintenance has been deferred. The procedure just described is followed for whatever other missions the aircraft is able to fly, until the aircraft is assigned. If it still has not been assigned to an alert force or to a scheduled flight, it is committed to the mission to which it was tentatively assigned during the postflight inspection and is associated with the other spare aircraft configured for that mission.

In the event the aircraft had returned from its previous mission with its munitions on board and it is assigned to a different mission, the munitions are returned to stock without any specific delay or requirement for personnel or equipment. Since the new mission will probably require that the aircraft be reconfigured, it is assumed, in effect, that the munitions downloading is a part of the reconfiguration process.

AIRCRAFT RECONFIGURATION

After an aircraft has had its next mission assigned, TSAR checks to see whether the TRAP with which the aircraft was equipped for the previous mission are appropriate for the next mission. If not, they must be removed and the aircraft must be reconfigured.

A review of the determination of the appropriate weapons load is in order. For each aircraft-mission combination, the user may specify up to five different standard combat loadings (SCLs); these should be ordered with the most effective munition first. The characteristics of an SCL include an aircraft configuration and one or two sets of munitions, each with a specified requirement for personnel, equipment, and time. Each configuration, in turn, is characterized by one or two sets of TRAP, each with its requirements for personnel, equipment, and time.

When new TRAP requirements are established, TSAR checks their on-base stock levels. If either the munitions or the TRAP required for reconfiguration are not available, the next most effective SCL is checked. If the resources are insufficient for any of the SCLs, the task must wait. The task must also wait when there are sufficient munitions and TRAP but insufficient personnel and equipment. Cross-trained personnel may be substituted for the normal personnel requirement for those tasks and on those bases that have been specified. When all resources are available, the appropriate munitions and TRAP are withdrawn from stock, and the time for the reconfiguration task is computed on the assumption that it will take the same amount of time to download a set of TRAP as is required to upload that set, but that the personnel and equipment associated with the new set of TRAP will perform the job.

MUNITIONS LOADING

When reconfiguration is complete the munitions are loaded. Since the required munitions are set aside when the requirements for reconfiguration are checked, all TSAR does is check on the facility itself, when specified, and on the personnel and equipment required for loading the munitions. If they are available (substitute personnel may be used when specified) the tasks are initiated. If only one of the subtasks may be initiated, the other is placed in the wait queue.

REFUELING

Refueling is included among the preflight tasks, but it does not have a rigid relationship with the other preflight tasks. Refueling is scheduled with the task-shop sequence outlined in Sec. IV. This task may be placed last or first, or grouped with other shops. Furthermore, the refueling task may have its own list of incompatible tasks, just like an unscheduled maintenance task. The only feature unique to this task is the requirement for a quantity of POL. The amount of fuel required is taken to be a characteristic of the aircraft type; the other resources required for refueling are similar to those for an unscheduled maintenance task.

MUNITIONS BUILDUP

Although munitions buildup is discussed here in connection with the other munitions related activities, it is a completely distinct set of off-equipment functions that are managed independently of the aircraft related tasks in a separate set of subroutines. Resource requirements for the buildup of each type of munition are specified in much the same manner as simple parts repair jobs, but the procedures used to schedule and prioritize these assembly activities are unique to these tasks.

The periodic aircraft supply and sortie demand projections (Sec. V) provide the basic "operations" data that drive the weapons buildup selection and prioritization logic. The munitions needs are checked every two hours immediately after those projections have been made. TSAR prepares a tally of all on-base munitions that are loaded, assembled, being assembled, or waiting to be assembled. For each base, another tally is prepared of the munitions assembly tasks that are expected to be completed within the next two hours. The sorties that are projected to be flown are then tabulated in terms of launch time, priority, mission, and aircraft type, base by base. Flight times within the planning time-horizon are divided into ten time blocks. To provide a proxy for the munitions demands by aircraft assigned to alert, it is assumed that those aircraft will be launched in both the first and the third time blocks.

These sortie demands are then converted into the munitions that are demanded by the preferred SCL for each particular mission and aircraft type; TSAR then checks to see whether sufficient munitions are available or committed. The checks are made first for the highest priority missions in the first time period, then for the next priority, etc. Following that, the demands in the second time block are checked, etc. Whenever sufficient munitions are not available or have not been scheduled to be built, a weapons buildup task is defined—if sufficient unassembled munitions are available—and a check is made to see if the required personnel and equipment are available (substitute personnel types may be designated). If tasks cannot be initiated they are placed in a wait queue until the number waiting equals the number of tasks that are expected to be completed before munitions requirements are checked again. If sufficient unassembled munitions are not available, the adequacy of munitions for less effective SCLs (for that particular mission and aircraft type) is then checked. If no munitions can be located, the demand is dropped. This process continues for all priority levels and time blocks, for each base in turn. Buildup demands generated by sorties in the later time blocks that cannot be initiated are dropped on the premise that they will be reexamined in the next two-hour review, and need not be queued at this time.

If the munitions assembly resources are not fully committed to the immediate demands, they may be used to build a reserve: The choice of the munitions to be assembled is based on the existing supplies and the history of the demand for munitions.

VII. PARTS AND EQUIPMENT REPAIR JOBS

TSAR provides the user with features that permit the examination of a wide variety of questions related to parts stockage and parts repair policies. Indeed, a variety of questions concerning autonomous and consolidated parts repair capabilities within the theater were central in shaping TSAR's theater characteristics. In its present form, TSAR may be used without any consideration of aircraft parts, with autonomous airbase parts repair facilities, with repair in whole or part at other operating bases, with a centralized parts repair facility in the theater, or with a combination of the last three modes. The constraints imposed by faulty support equipment may also be included in the TSAR simulation.

A specialized set of subroutines handles the several elements of the parts and equipment repair procedures. The first three of these subroutines can be designated to compute initial parts stockage, and the initial state of the spare-parts pipelines both from CONUS to the theater and, when there is a CIRF, from the CIRF and the operating locations. Other subroutines are used during the simulation; the first determines the appropriate length of the administrative delay to be imposed before the repair may be begun; a different delay distribution may be specified for each shop. Following that delay, other subroutines check on the availability of resources, store the repair jobs that are initiated, and conclude the repairs; another special subroutine is available to disassemble LRUs to obtain SRUs. When parts are repaired at a CIRF, other subroutines come into play. These latter procedures will be outlined briefly later in this section and discussed more completely in Secs. X and XI.

INITIALIZATION OF PARTS INVENTORY AND PIPELINE DATA

Although the user may enter the initial parts inventory and pipeline data for each base, much as for the other classes of resources, he may instead elect to have those data generated as an integral part of the input and initialization process. When this option is elected (for some or all bases), the nominal quantities of parts that should be procured for each base are determined according to the standard computational procedures outlined in Chapter 11 of Air Force Manual 67-1 or, for WRSK kits, with an approximation to the cost-sensitive DO-29 procedures. For in-theater units, both POS (peacetime operating stocks) and BLSS (base level self-sufficiency stock) are assessed. In their most basic form, those procedures estimate the number of each type of part to be procured as the sum of (1) the expected number being repaired on base, (2) the expected number that are undergoing repair off base, and (3) an additional number to hedge against stochastic variations in the demand.[1]

The estimates are made on the basis of (1) the parts-procurement-policy planning factors that the user enters, (2) the expected daily demand rate for each part based on the task and parts-repair probability data, and (3) the NRTS data entered for each part. If desired, the user may specify different safety factors for LRUs and SRUs, and for those tasks that may be deferred indefinitely and those that may not.

For units that are deployed to the theater, the nominal parts allowance, or WRSK, may be computed by either of two procedures. In the first procedure the allowance is computed on

[1]The user may augment these computed stock levels to cover expected battle damage etc.

the basis of 30 days' supply at the planned wartime sortie rate for the RR items, and the same as for BLSS for the RRR items. A 30-day supply of SRUs is included for the LRUs that are RRR, unless they may themselves be repaired in the theater. With the second procedure, the WRSK allowance is computed in accordance with an empirical algorithm that approximates the cost optimization procedures used in the AF DO-29. If the user desires to simulate parts shortfalls relative to the computed levels, he may specify that all types of parts are short by a specified percentage, or that a user-specified percentage of the part types selected at random are short by some other percentage; alternatively, he may choose to introduce both categories of shortage statistics.

As discussed in Sec. IV, aircraft spare parts for rear maintenance bases are either entered directly or, when the automatic parts generation feature is being used, they are provisioned by redistributing the spares that have been calculated for the operating bases. For tasks that must be done in the rear, all parts are placed in the rear. An estimate is also made of the fraction of the other tasks that will be accomplished at the rear base at the same time that the mandatory work is underway, and a similar fraction of all parts is placed in the rear. If aircraft are also sent to the rear whenever the ready-to-fly time exceeds the user specified limit, the fraction of the parts placed in the rear can be increased by a user specified percentage.

When the user is examining CIRF operations, other considerations affect the parts initialization process. For the procurement computation the user may (1) take account of or neglect the effect of the CIRF on NRTS rates, and (2) take account of or ignore any advantages of scale in the SRU computation. When the first is neglected, the NRTS rates that are used for computing the number of parts to be procured for each base are those that would apply if there were no CIRF. When the second is neglected the number of SRUs is the sum of those computed for the individual bases, even though all the LRUs may be repaired at the CIRF. If the latter is not neglected, the SRU procurement computations reflect the scale advantages to be expected when the demands for several bases are consolidated at a CIRF.

The authorized level of stock computed for each base assumes that all serviceable LRUs are at the operating locations. SRUs, however, are allocated in the same proportions as in-theater work on the parent LRU. Thus, without a CIRF, all parts are at the operating bases, but when a CIRF is introduced, some of the SRUs will be at the base and some at the CIRF for LRUs that are repaired partly on base and partly at the CIRF.

After the nominal parts level and the available number of serviceable parts have been computed and stored for each type of part at each base, the parts pipelines are initialized. When there is no CIRF, the parts that are in the pipeline are scheduled for delivery within the user-specified order-and-ship time, with the actual day picked at random for each item. When a CIRF is assumed to be present, there will be some items in the base-CIRF-base pipelines and others in the CIRF-CONUS-CIRF pipeline. TSAR estimates the mean numbers in each pipeline for each type of part on the basis of the user-supplied data regarding the various times and the daily demands generated at the operating bases. Items are then positioned in both pipelines for delivery after the simulation is begun.

INITIALIZATION OF STOCKS FOR BATTLE DAMAGE REPAIRS

Parts also may be stocked automatically for repairing battle damage sustained in air operations. The quantities stocked at each base depend on a specified number of sorties for each of a specified number of aircraft and on the average battle damage rate expected during

the first 30 days of conflict (assuming the various mission types are flown equally). The number of aircraft is the initial number on base, or, when parts are provisioned automatically, the number of aircraft specified for the spares stockage algorithms. The stocks of these battle-damage spares that are allocated to the various operating bases take into account any task specifications that mandate the task be accomplished at a rear base. The allocation also takes into account (at least approximately) the likelihood that some tasks normally done at the operating base will actually be cleaned up when an aircraft is in the rear for mandatory rear-area maintenance.

ON-BASE PARTS REPAIR

Whenever an attempt is made to initiate an on-equipment task and a faulty part is found (or a faulty SRU is found during the repair of an LRU), the part is set aside for a delay time before the actual repair process may be initiated. For a part removed from an aircraft the delay is equal to the sum of the mean time for the on-equipment task (to simulate the time for removal) and an administrative delay. (The user specifies the mean and distribution for this delay by shop and by base.) The user may elect to have the administrative delay reduced or eliminated when no serviceable parts are on hand; this action can be used to simulate the measures that might be adopted in wartime to expedite the repair of needed parts.

When the delay is complete, TSAR checks first to see whether the part will have to be repaired elsewhere (is to be NRTSed), or whether it can be repaired on base; this is done by comparing a random number with the NRTS rate. The resources required for the repair process are determined next. The user may specify one or more repair procedures for each type of part: One is assumed to apply when it is determined that the part is to be NRTSed; if the part is to be repaired on base and has two or more possible repair procedures, TSAR uses a random number to identify the required procedure using the data provided as to the likelihood that one or another of the procedures is required. Each parts repair procedure can specify requirements for a number of one type of specialist, one or two types of equipment (including a particular AIS station), and time; if the part is an LRU that may have a defective SRU, each SRU is specified by including it as an additional requirement in an LRU repair procedure.

TSAR next checks whether the shop has been closed by air attack and, if not, whether the necessary personnel and equipment are available. If they are not, the repair must wait; when those resources are available, a check is made to see if the part is to be NRTSed, or if an SRU is required for the repair. If it is to be NRTSed, the part is consigned for shipment, and the personnel and equipment that are required are committed for the specified time (the timing error in dispatching the part before the time has expired is neglected for convenience in coding and processing).

If the part is to be repaired on-base, and an SRU is defective, the faulty SRU is withdrawn and subjected to an administrative delay. Then checks are made to see if a serviceable SRU is in stock. If none are available and an aircraft is NMCS for the LRU, the user may specify that another LRU may be sought in the wait queue and disassembled to obtain its serviceable SRUs—be cross-cannibalized. If the LRU repair job still cannot be started because of the shortage of an SRU, it is placed in the wait queue of the appropriate shop.

If the user has specified that jobs that must wait are to be rank ordered, rather than ordered FIFO, the repair job is placed in the wait queue such that emphasis is placed on those

parts that are most likely to be required next. Algorithms other than the one now prescribed could easily be inserted in the code, if the user preferred to consider a different set of rules.

When the two-hour administrative delay for SRUs is completed, TSAR checks to see whether the SRU is to be NRTSed, or whether it may be repaired on base, much as for an LRU. Checks are next made to see if the required personnel and equipment are available to start the prescribed repair procedure. If they are not, the repair must wait; if they are, the SRU is NRTSed when appropriate, and the personnel and equipment committed for the specified time—again much as for an LRU.

When a parts repair job has been completed, a check is made to see if there are aircraft on base that require a part or LRU of the type that has been repaired. If there are, and the aircraft is on base and is currently undergoing unscheduled maintenance, the appropriate on-equipment task is initiated. The first aircraft found that meets these requirements is selected. Similarly, when an SRU repair is completed, resources are sought to repair an LRU that requires that SRU.

OFF-BASE PARTS REPAIR

When a faulty part is found to be NRTS, TSAR checks to determine where to ship it for repair. Different destinations may be specified for each type of part. If the part is shipped to another operating base, TSAR treats it as if it were any other job generated at that base, and it undergoes an administrative delay. However, the number of the originating base is preserved so that the part may be returned when repaired. Depending upon the NRTS rate for that type of part at the receiving base, the part could be shipped to yet another base; if it is repaired at that base, it will be shipped back directly to the originating base when repairs are completed, unless the user has specified that all repaired parts should be consigned to that base with greatest need.

When a reparable part is shipped to a CIRF it is subjected to an administrative delay; then a different set of rules governs its priority and disposition. Section XI outlines these more fully. (The properties of the transportation and information nets used in connection with these operations are explained in Sec. X.) Parts repair times at a CIRF can be modified by the user to account for the different working conditions; these modifications can be controlled on a shop-by-shop basis.

If a part is condemned or shipped out of the theater, its replacement, when one is specified, is consigned for delivery directly to the base of origin, even though a CIRF may be operating, unless the user has specified that parts distribution is to be centrally managed. In the latter case, all parts returned from CONUS are consigned to the theater manager for transshipment according to the user-specified theater resource management algorithms.

SUPPORT EQUIPMENT REPAIR

Many special kinds of support equipment are needed for the specialized jobs that must be conducted on a modern military airbase. Most of these equipments are both complex and expensive with frequent malfunctions; their maintenance and repair constitute an essential set of activities. Such malfunctions and the repair of faulty equipment may also be simulated in TSAR.

Support equipment repairs are handled in much the same way as spare part repairs, and with many of the same subroutines and procedures. However, TSAR provides two quite dif-

ferent representations of equipment failure and repair. The simpler representation is used for all equipments except the complex equipments used to test and repair avionics on late model aircraft. The basic distinction is that in the simpler representation, either equipments are serviceable or they are not, whereas the more complex AIS equipment may be partly mission-capable as well. Both representations are described below.

Equipment Repairs Other than AIS Sets

Whenever a task that has used support equipment (other than an AIS set) has been completed, TSAR checks each item of equipment to see if it needs maintenance. This is done by comparing a random number with the probability that that type of equipment will require maintenance following a job. If it is determined that maintenance is required, the equipment first undergoes an administrative delay, much like that for spare parts, although the length of such delays may be different. After the administrative delay, the attempt to initiate the repair is processed with the same subroutines as a faulty aircraft part. As with parts, each type of equipment is associated with a particular shop, and the repair procedure may either be specific or be chosen at random from among a set of alternative procedures. Equipment repair procedures specify a type and number of personnel, one or two pieces of repair equipment, and a duration; and, as with other kinds of simulated tasks, alternative procedures may be specified for consideration when the normal resources are not available. But these specifications do not include the spare parts that might be needed to repair the equipment; such problems can be approximated by specifying that equipment repairs can be carried out without delay for parts on some occasions, while on other occasions they are subjected to a delay equivalent to the order and ship time for spare equipment parts.

If resources are available when an equipment repair is first attempted, the resources are assigned to the repair, the completion time is established, and the job is placed in the repair queue: if resources are not available, the job must wait. Equipment repairs that must wait currently are handled on a first-come, first-serve, or FIFO, manner; if equipment and parts are competing for the same repair personnel or equipment, the equipment repairs are given priority over spare parts for which serviceables are available, but must follow the repairs for parts needed for work on aircraft. As currently structured, all equipment repairs are performed on base; equipments are not NRTSed to other bases.

Simulation of AIS Maintenance and Repair

TSAR may also simulate the specialized support equipment used for testing and repairing avionics on late model aircraft—the AIS. A full "string" of AIS will normally have several different complex electronic test equipments, or "stations," and each type of station tests several different LRUs. Each station is composed of many hundreds (thousands) of sub-modules, and these stations are themselves subject to various malfunctions that can require substantial maintenance. Furthermore, when any of the numerous low-failure-rate (and therefore unstocked) AIS parts fails, it is necessary to order one from another location, and that station will then be able to test only some portion of its normal LRUs. Thus a station will be in one of three states: fully mission capable, partly mission capable, or inoperative. If two or more stations of the same type are available at an airbase, partial mission capability generally is minimized by consolidating all missing parts at one station.

The way these characteristics are modeled in TSAR is adapted from Refs. 12-14. When

an AIS station is used to repair an LRU or SRU, the nominal part repair time is increased to allow for maintenance of the station itself. Since such maintenance may actually occur either before or after, or even during, the repair of the part, it is assumed that the part is not released until the job is completed. At that time, the LRU is released for use and TSAR checks to see if any piece part that was needed for maintenance of the AIS was not in stock. If the AIS repair could not be completed, the station's residual capability to repair LRUs is estimated on the basis of statistics that indicate the likelihood that the capability to repair a particular LRU is lost when an AIS part must be back-ordered. To accomplish this in TSAR we imagine that each station is divided into a number of "trays," with one tray for each type of LRU that is repaired by that type of station; when TSAR determines that a part is back-ordered the mission capability of each tray is determined by comparing a random number with the appropriate statistical data.

During the simulation, a check is made following each LRU repair to see whether an AIS station was found to need a part that is not in stock. If one is needed, but two or more stations of that type are on the base, it is assumed that the needed part will be cannibalized from another station, if necessary, and that all missing parts are consolidated at one of the stations. Thus, when an AIS part fails at any station, checks are made for each LRU tray associated with that type of station and a list is generated of all LRUs that cannot be repaired until the needed part is obtained. A sample is then drawn from the user-specified order-and-ship-time distribution, and the appropriate receipt time is recorded; not until that time is the capability for repairing those LRUs restored.

There are no specific repair procedures, personnel, or equipment used to repair AIS equipments. Instead, the repair time of each part processed is increased to account for AIS maintenance, and AIS repair capabilities are probabilistically curtailed to simulate a shortage of parts to repair the AIS.

VIII. AIRCRAFT SORTIE DEMAND AND AIRCREW MANAGEMENT

The ultimate objective of an airbase is to provide combat capable aircraft when they are required, and a base's capability for meeting that objective can depend upon the pattern of the demand. In TSAR, the user's input data controls that demand pattern, and the user has sufficient options that most plausible requirements should be readily represented.

A demand for a flight of aircraft specifies the type of aircraft, the mission, the mission's priority, and, normally, the base; it also specifies the number of aircraft to be launched (and the minimum acceptable number), the time they are to be launched, the time that the airbase is informed of the demand, and the recovery base. If desired, the user may also specify that a number of aircraft will be maintained on alert at a particular base for unscheduled demands. In addition, he may define a composite flight made up of several sets of aircraft or flights, each with a differing configuration, as would be required, for example, for representing coordinated attacks by defense suppression aircraft, CAP, and CAS aircraft.

Except for composite flights and specified alert forces, it is not mandatory that the launch base be specified. If the user specifies, TSAR estimates each base's sortie generation capabilities daily; these estimates are used as the basis for designating a base for any sortie demands for which a base has not been specified. But because TSAR does not include geographic concepts, such selections will not be constrained by range-to-target considerations.

GENERATING SORTIE DEMAND DATA

The sortie demands for each day and for subsequent days are reexamined each evening at 2000 simulated time. If the user wishes to specify new flights or to change specifications for alert forces or periodic flights, these data are input at this time. If there is no new information, the following day's demands are based on the periodic flight demands or other flight data that were submitted earlier. Any flight demands for which a base has not been specified are designated for the base with the lowest current level of demand relative to its estimated sortie generation capabilities, based on updated estimates of the bases' sortie generation capabilities that are created daily at 1930 hours.

If an airbase is out of operation because its runway is closed at the time that the sortie demands are organized for the following day, the demands on that base may be reassigned. If the runway is projected to remain closed for any part of the following day, and other bases have aircraft of the type specified, those demands that are required to be met before the runway is to open are either reassigned as though the launch base had not been specified, or are reassigned in proportion to the numbers of aircraft on base. Demands to be met after the runway is scheduled to be reopened are not reassigned.

Provisions have also been made for entering other endogenously generated flight demand data. These provisions would be used if and when the resource management logic is expanded to permit endogenous decisions regarding sortie demands. If the base is not specified, that base best able to fill the demand is selected.

LAUNCHING THE AIRCRAFT

At the time specified for launching aircraft, TSAR checks the weather conditions and runway. It also checks the aircraft that have been assigned for a scheduled flight, or are available in the alert force, to see if they have been readied for flight and, if not, whether they will be ready within the time allowed for late takeoff. Access to the runway over the network of taxiways is also checked for each aircraft.[1] If aircrews are to be accounted for, they are located and tentatively assigned to the aircraft.

If fewer than the required number of aircraft have not been assigned to meet a specific demand, and if the periodic check of aircraft availability (Sec. V) indicated that the demand could be met, other aircraft are checked. The spare forces are checked first and then later flights of the same and lower priority, and finally the alert forces of lower priority; these are each checked in turn for a ready aircraft of the appropriate type and mission configuration. If, after all these sources are checked, the number of aircraft available to meet the demand is less than the minimum permissible number, the flight is canceled. If their number is sufficient, they are launched.

As each aircraft is launched it is checked for an air abort; if one is to occur, the aircraft is scheduled to land with a full load of munitions at the launching base after a six minute flight. It is handled like any other aircraft in the ensuing postflight inspection except that attrition and battle damage are not assessed. If an aircraft is designated to recover at a different base, that bookkeeping is also accomplished at the time that the aircraft is launched. The flight times for each aircraft in a flight are determined independently, unless *recovery* as a unit has been specified for that type of aircraft and mission.

AIRCREW MANAGEMENT

Aircrew members are accounted for on an individual basis, much like aircraft. Each aircrew is qualified for only one type of aircraft. TSAR manages aircrew assignments so that each crew will receive a specified minimum amount of uninterrupted sleep during each 24 hour period and a specified minimum rest between sorties. To avoid unnecessarily long shifts and early exhaustion it is presumed that aircrew assignments can be managed such that they remain off duty until they are needed and will retire early whenever the demand permits.

---

[1] At the present time the runway access probability depends upon the user's appreciation of the problem (see p. 40). If time permits, I plan to introduce a more sophisticated logic that will take into account the actual network of taxiways and the specific pattern of damage.

IX. AIRBASE ATTACK AND RECOVERY

The most serious disruption that an airbase can experience is undoubtedly that associated with a heavy airbase attack. The inability to estimate the effects of such attacks on a base's capabilities to recover and generate useful aircraft sorties was the prime motivation for TSAR's development. The fact that the damage patterns are highly irregular contributed to the decision to create a model with sufficient detail to capture the critical effects of the highly stochastic damage patterns. Unless one included the possibilities for localized bottlenecks as well as for emergency and alternative procedures, one could hardly hope to represent the probable behavior of an airbase during the crisis following an attack.

SPECIFICATION OF ATTACK CHARACTERISTICS

In TSAR, airbases are attacked and resources are damaged or destroyed in accordance with the specifications supplied by the user on the basis of independent damage calculations. The user is free to schedule attacks at whatever times and against whichever bases he chooses, and TSAR has been structured to accept highly detailed damage data. The user enters these data at the beginning of the simulation.

The damage data supplied by the user for each attack are expressed in terms of the percentage damage to the resources at risk at the time of the attack. The user can specify such data independently for each type of each of the 11 classes of resources. For aircraft and facilities, the damage data are expressed separately for the aircraft or facility, and for the personnel, the equipment, and the aircraft spare parts associated with the aircraft or facility at the time of the attack. By introducing damage data in terms of a percentage of the resources at risk, the user can make the damage calculations independent of a precise knowledge of the base's status at the time of the attack.

USE OF THE TSARINA COMPLEX-TARGET DAMAGE ASSESSMENT MODEL

A special version of the AIDA model has been developed to provide these data for TSAR. Dubbed TSARINA, for TSAR INputs using AIDA, this new computer model accepts detailed descriptions of the location, construction, and contents of various airbase facilities, as well as detailed specifications of enemy attacks and weapons effectiveness factors, and converts the resultant Monte Carlo damage estimates into the exact format required by TSAR.

TSARINA permits damage assessments of attacks on a airbase complex that is composed of up to 500 individual targets (building, taxiways, etc.), and 1000 packets of resources. The targets may be grouped into 20 different vulnerability categories; and many different types of personnel, equipment, munitions, spare parts, TRAP, and building materials can be distinguished. The attacks may involve as many as 50 weapon-delivery passes and 10 types of weapons. Both point-impact weapons (such as general-purpose bombs and precision-guided munitions) and area weapons (such as cluster bomb units) can be accommodated.

TSARINA determines the actual impact points by Monte Carlo procedures—i.e., by ran-

dom selections from the appropriate error distributions. Weapons that impact within a specified distance of each target are classed as hits, and TSARINA estimates the damage to the structures and to the various classes of support resources using "cookie-cutter" weapon-effects approximations.

For each trial computation of an attack, TSARINA determines the fraction of each target covered by the circular damage patterns, and the results include estimates of the overall damage to each target and to all resource classes that are collocated with that target. In addition, the TSARINA output includes an estimate of the total percentage of each type of resource that was damaged at its various storage locations. These latter data are formatted to be loaded directly onto disk for immediate processing by TSAR or to be stored for subsequent use; no manual data conversion is required.

For runways and other large surfaces, TSARINA tests to see if any of these will permit emergency flight operations. It searches for an undamaged area of the prescribed minimum size, which may be either rectangular, or rectangular with a superimposed triangular clear area as is needed for cable clearance with a mobile arresting barrier. If no clear area is found, TSARINA locates the area that would require the minimum number of repairs. That number is reported to TSAR as the runway damage. TSAR prohibits aircraft operations until base engineers have repaired the damage.

Bomb damage to taxiways is handled quite differently. TSARINA reports the total number of craters in designated taxiways as a percentage of a user-specified number, and TSAR assesses how taxiway damage affects aircraft access to the runways based upon the user's appreciation of the problem under analysis. His choice of input parameters controls how the "probability that an aircraft can gain access to the runway" varies as a function of that damage percentage. The relationship he prescribes may be linear or, as would usually be more appropriate, highly nonlinear so that access can generally be greatly improved with only a limited amount of repair.

RESULTS OF THE ATTACK

At the stipulated time an airbase attack is to occur, TSAR executes several operations in sequence. The base stocks of the various damaged resources are decremented first; that process is straightforward for losses to off-duty personnel, munitions, TRAP, building supplies, and the residue POL storage; it is somewhat more involved for on-duty ground personnel, aircrews, aircraft, aircraft shelters, and other facilities. For those resource classes specified by the user, orders are made to replace the losses; such resources arrive following the delay specified for such shipments.

Aircraft shelters may be represented in TSAR, and a subset of those shelters may be designated for use by aircraft that are on alert. If there are more aircraft on base than may be sheltered, the unsheltered aircraft are selected at random from among the non-alert aircraft, and the remainder are assigned to a shelter with the alert aircraft assigned first to the alert shelters. A random number is drawn for each unsheltered aircraft and compared with the likelihood that unsheltered aircraft are damaged. Each shelter is then checked to see if an aircraft would sustain damage if the shelter door were open. If there are aircraft in the shelters that are so exposed, a check is made to see if ongoing tasks would require the shelter door to be open; if so, the aircraft is damaged. If not, a check is made to see if the aircraft is damaged even with the doors closed. Different damage probabilities may be considered for the alert shelters and for the other shelters. Each damaged aircraft is also checked to see

whether it is reparable or whether it is suitable only for salvage. If the user has stipulated a damage percentage for personnel or equipment, the on-equipment tasks that were happening at the moment of the attack are each checked, and TSAR determines the survival of the associated personnel and equipment by comparing random numbers with the specified loss rates for these resources for each aircraft damaged in the attack. If resources associated with the task are lost, they are eliminated. If an aircraft is not reparable, it is next checked for parts that may be cannibalized for stock. For each part on the aircraft's parts list, TSAR compares a random number with the specified parts loss rate to determine if the part survived. If it has survived it is placed immediately into the base's stock of serviceables. The time to remove the parts is neglected on the assumption that that operation would be conducted as time permits. The user may specify that lost aircraft are to be replaced with aircraft from CONUS, or by filler aircraft that are held in reserve in the theater.

When any of the other facilities are damaged, another procedure is followed. For these targets the user-supplied damage data may include the percentage of the facility that is damaged as well as the percentages of the personnel, equipment, and parts that are lost.[1] The personnel and equipment considered at risk when a shop facility is hit are those engaged in parts repair jobs and those on duty at the shop and unassigned. If the user has designated that the activities of a particular shop are carried out at more than one location, the personnel and equipment that are at risk at each location are assumed to be in the same proportions as the user-specified job capacities at each previously undamaged location. Unless personnel and equipment have been assigned to individual aircraft squadrons, all on duty unassigned personnel are assumed to be in the shop; if they have been assigned to a squadron, the flight line personnel for each squadron are assumed to be in other specific facilities. The unassigned on duty personnel and equipment first are checked by type and those assigned to a damaged facility are decremented appropriately. For those engaged in parts repair jobs TSAR checks the shops individually. For each shop that was hit, the off-equipment jobs are checked and the associated resources are reduced accordingly. When the repair capacity of a particular shop is distributed in more than one location, the reparable parts and faulty equipment that are being repaired, or are waiting to be repaired at the time of the attack, are assumed to be proportionally distributed among the undamaged locations according to their capacities. If all elements of a shop are damaged from prior attacks, the user specified value of the appropriate control variable designates whether the vulnerability of these resources is zero or the same as they would be if the shops were undamaged.

After the damage to the shop facilities has been processed, TSAR reorganizes the surviving ground personnel. If some of the personnel have been assigned to flight line units and some to the parts repair shops, all of the personnel of the same type in the several base organizations are regrouped in the proportions implied by the "target levels" that the user specifies for each group of personnel; and then each group is divided into day and night shifts in the proportions implied by the "target" levels; this is done for all personnel types that suffered losses. An equivalent reorganization is performed for the equipments that survive the attack. If the user has specified an amount of time by which aircraft maintenance activities can be expected to be disrupted, all tasks still in process on surviving aircraft, except for preflight tasks, and in undamaged shops, are extended by that amount of time. If any affected aircraft have been scheduled for a late takeoff, the aircraft and crew assignments are canceled.

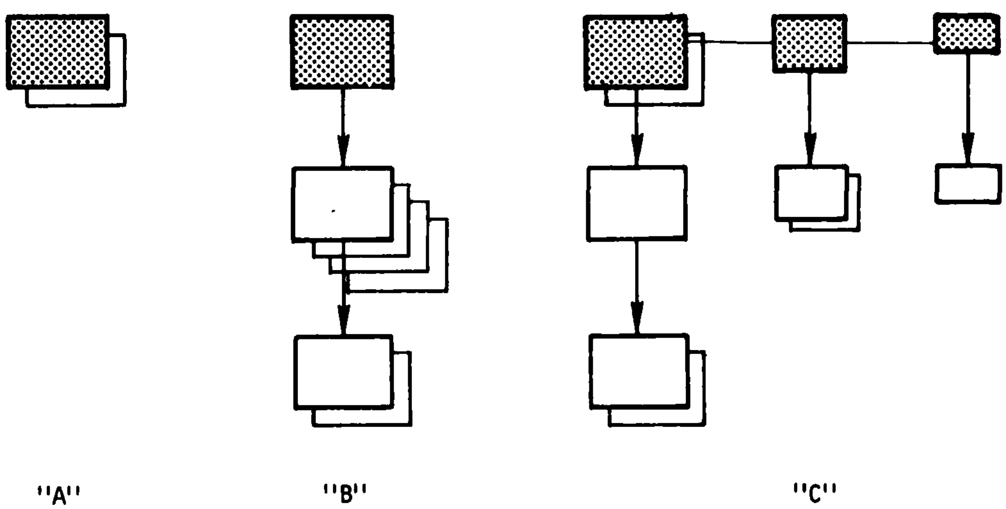
[1]The user may exercise an option that disassociates the resource loss rates from facility damage by designating the overall loss rate for specific resource types; when this has been done, these specific rates override any resource loss rates entered with the facility damage data.

Before the damage suffered by the facilities themselves can be dealt with, it is first necessary to estimate the current status of the facilities that had been damaged in previous attacks and that are being repaired at the time of the attack. It is assumed that the percentage of the original damage that has been repaired is equal to the percentage of the repair time that has passed. When the old damage has been updated and all civil engineering resources have temporarily been returned to stock, the present damage level is estimated. It is assumed that the damage due to the prior attacks and the damage from the current attack are independent and that they combine as $D = 1 - (1 - D_1)(1 - D_2)$, where D_1 and D_2 are the old and the new damage fractions.

When the repair of a facility requires a sequence of procedures a check is made to see if any part of that work sequence remains from a previous attack—i.e., if the facility is still undergoing repair. If it is, the amount of damage (work) remaining for each step of the procedure is determined as noted above; that is, the residual damage at the time of the attack and that imposed by the attack are combined as though they were independent. Unless a specific damage level is entered for a step subsequent to the first, all steps are assumed to sustain the same percentage damage.

POSTATTACK RECOVERY AND RECONSTRUCTION

The TSAR can also represent the actions of the base engineers and other civil engineering resources in carrying out the emergency repairs essential for restoring critical functions. The optional representations of on-base facilities and the civil engineering procedures for restoring operations at those facilities are depicted below:



The shaded blocks constitute actual facilities, as well as repair procedures. Thus "A" depicts the situation in which the activities of a given shop are carried out in a single location and damage to that facility can be repaired using either a basic repair procedure, or—the backup blocks—one or another alternative procedure. Situation "B" depicts another shop whose activities also are conducted in a single location, but three sequential civil engineering procedures are required to restore shop operations. Situation "C" is a distributed shop whose

activities are carried out in three distinct locations, each of different size and capacity; the main location requires a three-step process to restore operations, whereas the auxiliary locations require only two steps.

When a building is damaged, TSAR combines the size of the building and the percentage damage to determine the magnitude of the reconstruction job. The requirements for repairing facilities are filed for each type of facility. Some number of each of two types of civil engineering personnel and equipment may be specified. Requirements for each of two kinds of building materials may also be specified. (At this time, TSAR does not consider the reconstruction of aircraft shelters.)

The time and the quantities of (up to) two types of building materials that are required to repair each type of facility are specified in terms of the requirement for one "unit" of reconstruction; the size of such a "unit" is defined by the metric the user chose in specifying the size of the facilities of that type. In light of the possibilities for highly nonlinear relationships between the repair time and the magnitude of the damage, the user is provided with 84 optional relationships that he may select to relate the repair time to the level of damage.

To facilitate the prioritization of civil engineering resources for the repair of the various damaged facilities, the user is required to provide a priority listing of the facilities in the order in which they should receive attention; he also must indicate how many facilities on the list are especially critical. The same list is presumed to apply to all bases.

The first task is to check whether the civil engineering personnel, equipment, and building materials are sufficient to initiate repairs of all damaged facilities in the critical range. If they are, the personnel and equipment are allocated and sufficient building materials are withdrawn from stock to complete the jobs. If the civil engineering resources are insufficient to start all critical tasks, the allocation starts with the highest priority facility that is damaged and proceeds until resources are exhausted as just described, except that an alternative, lower demand procedure is adopted whenever one has been specified. To reflect the various disruptions that are not dealt with in this formulation, but would delay the initiation of all reconstruction—e.g., fires, roadway damage, etc.—the computed reconstruction times may all be increased by the user-set value of the appropriate control variable. When a CIRF is used in the simulation, each damaged shop on the operating base is checked to see if the parts could be shipped to and from the CIRF in less time than it is projected to take to repair the shop; if so, the faulty parts are shipped. Also, the CIRF itself may be subjected to an air attack.

X. COMMUNICATIONS

TSAR allows for the representation of scheduled shipments of material from CONUS to the theater, special shipments from CONUS in response to theater requests, intratheater shipments of resources, and the transmittal of airbase status information. The schedules for each of these types of transfers are controlled by the user's specifications, as are the contents of scheduled CONUS shipments; the contents of the other transfers are generated endogenously.

SCHEDULED SHIPMENTS FROM CONUS

The user must initially specify resources scheduled to be delivered from outside the theater after the simulation begins. The only resource classes that may not be shipped from CONUS are aircraft shelters and other facilities. When new ground personnel arrive they are added to the day and night shifts to maintain the ratio of the shift sizes in the same proportions as specified by their "target" levels. TSAR then checks to see whether they may be assigned to a task. The same is done for equipment and aircraft spare parts when they arrive on base. When aircraft are ferried to the theater from CONUS they are added to the inventory at the appropriate base and undergo a normal postflight inspection, except that attrition is not checked. The delivery aircrew is attached to the base's flight staff and given 24 hours to rest before their first assignment. Aircrews that are ferried to the theater (arrive without aircraft) are treated in the same manner.

RESPONSIVE SHIPMENTS FROM CONUS

The user also may simulate the requisition and resupply of resources from CONUS for any class of resources except shelters and the other facilities. When operative, a requisition is submitted for resources that are lost in combat or during an airbase attack and, in the case of parts, for parts that may not be repaired in the theater. The resources requested are delivered after the delay specified by the user for each of the various resource classes. Arriving resources are treated identically to scheduled shipments described above.

INTRATHEATER SHIPMENTS

All resources except aircraft, aircrews, and facilities may be transferred from one base to another by means of an intratheater transportation system. The description of this transportation system is controlled by the user's specifications of the schedules and the statistics governing their delays, cancellations, and losses. Resources are not specified for making these shipments (e.g., trucks or aircraft) nor are the shipments capacity limited. They only represent the times expended between the time supplies are consigned for shipment and the time a shipment reaches its destination and the cargo is added to base supplies. The rules govern-

ing the transfer of resources with this intratheater transportation system are discussed in Sec. XI.

The user may specify daily departure times on an individual basis for each origin-destination combination. He may also control the mean departure delay, mean transit time, and the distribution of these values on an individual basis. Furthermore, a fraction of the shipments may be canceled; the commodities that had been prepared for that shipment are rescheduled for the next shipment. The user may also specify a loss rate for shipments between any two bases; the commodities on these shipments are not recovered. Any of the schedules may be changed at any time during the simulation in much the same manner as the demands for aircraft sorties.

As TSAR is currently formulated, the intratheater shipment system is restricted to the movements of faulty parts and to the shipment of ground personnel, equipment, and serviceable parts when unbalances are noted by the theater resource management system.

INTRATHEATER RESOURCE STATUS REPORTS

Although an exact count is maintained on the status of all resources on all bases throughout the simulation and these data could provide the basis on which various theater resource management systems might be examined, it seemed inappropriate to presume that the information available to such managers would be precise and up to date. Indeed, one of the greatest drawbacks associated with many centralized systems is their need for high quality communication and transportation systems. Unless it were possible to represent the inefficiencies of the systems that may actually be available for our forces, it would be reasonable to question the validity of the results of any examination of schemes for managing resources on a theater-wide basis.

TSAR permits the user to define one or more times each day for each base at which the then current status of the ground personnel, equipment, and aircraft spare parts are collected for a report to "theater headquarters"—i.e., to the theater resource manager. The user also specifies the time delay before that information would be formatted, transmitted, decoded, and available to that manager; the delay and the distribution of those delays are controlled by the user base by base. The completeness of the report also may be controlled in two ways; the entire report may be lost in a specified percentage of cases, or some percentage of the individual data may not be reported.

The particular status reports that are transmitted when the communication system is activated are controlled by the user's choice as to which classes of resources will be managed; he may select any combination of the ground personnel, equipment, and spare parts as explained in the next section.

XI. THEATER RESOURCE MANAGEMENT

TSAR's abilities to represent operations at a set of airbases, and to handle the transfer of various classes of resources among those airbases, can be combined to provide a unique mechanism for pretesting policies that would exert a broad span of control over theater resources. Indeed, some may view TSAR's prime role as a test bed for examining the effectiveness of new policy proposals. Although TSAR is currently concerned only with the theater-wide management of aircraft, ground personnel, and equipment in addition to faulty and serviceable aircraft spares, it could readily be extended to managing the other classes of resources.

The range of policy options that might be examined with TSAR is limited, obviously, to those decision rules that can be expressed in terms of the resource status information—past, present, and projected—available within this simulation. In TSAR there are basically three sets of status information: (1) accurate data regarding current status, (2) the delayed and imperfect data provided with the theater status reporting system, and (3) an approximate projection of each base's current capability to generate sorties. In addition, there is a limited amount of data regarding future sortie demands, as well as the completion times for all ongoing tasks. The range of decisionmaking policy options that could be evaluated with TSAR will be illustrated in the following discussions of the rules currently encoded in TSAR.

Several options are available for the decisions that govern the diversion and transfer of aircraft and the assignment of sortie demands when a base has not been specified. The simpler algorithms are based on the current numbers of on-base aircraft and the more complex on projections of the sortie generation capabilities at the various airbases. When aircraft must be diverted from their assigned recovery base, they are sent to the base that has an open runway and either the lowest surviving fraction of assigned aircraft or, in the more sophisticated mode, the highest sortie generation capability per available aircraft. Such aircraft operate at the alternate location until the runway at their parent base has been reopened or, in the more sophisticated mode, until that base's sortie generation capability per available aircraft is within a specified percentage of the capability at the alternate base.

TSAR offers several options for managing aircraft resources. Initially, aircraft may fall into three different categories—aircraft assigned to an operating base, aircraft in a theater reserve of "filler" aircraft, and replacement aircraft in CONUS. If the user designates a pool of "filler" aircraft, they may offset degradations due to lost and damaged aircraft, as well as aircraft with excessive maintenance requirements and those withdrawn to a rear base for maintenance. These fillers may be used in addition to, or instead of, a reserve of aircraft in CONUS for replacing losses. The user is provided several options as to how these aircraft are used and managed. The replacement aircraft, when specified, are used exclusively for replacing aircraft that are lost in combat or from the effects of air attack, or that have been so badly damaged that they must be salvaged. If the user specifies that both fillers and replacement aircraft are available at the beginning of the simulation, the losses will be replaced with a filler, and the replacement will join the filler pool when it arrives in the theater if it is not then needed at the operating base.

The algorithms currently encoded for theater management of support resources deal with the following four resource allocation decisions:

1. Periodic review and reallocation of ground personnel, equipment, and aircraft spares among the operating bases,
2. Acquisition of a spare part by an operating base,
3. Disposition of newly repaired serviceable spares, and
4. Choice among repairs waiting at a CIRF.

In several instances the user may select from alternative sets of rules for these decisions. The decisions, and the bases for these decisions, are outlined below. Although each of these sets of algorithms acts independently in the manner to be outlined there are instances in which one rule may be overridden or nullified by another. An obvious example occurs when a CIRF is directed to ship all newly repaired or newly acquired spares to one of the operating bases, and the operating bases are, in turn, directed to order a part from central supply at the CIRF; obviously such requests will always go unfilled if all parts have been shipped as soon as they become available. To fully understand the nature of the simulation it is clearly necessary for the user to be aware of how his choices for the various control variables affect the simulation, and what the interactions are among the variables.

MANAGEMENT OF FILLERS, AIRCRAFT TRANSFER, AND DIVERSION

TSAR options for managing the theater's aircraft resources are designed to simulate various decisions that theater managers would, in certain circumstances, attempt to make to enhance the sortie generation potential of their aircraft force. Included would be the replacement of lost aircraft, the insertion of reserve aircraft to offset aircraft immobilized by the need for extended maintenance, and the reassignment of operating aircraft in an effort to balance the maintenance workloads across airbases. Such situations could arise whenever bases suffer disproportionate losses of support resources or aircraft or when closed runways force aircraft to divert.

Management of Filler Aircraft

A pool of filler aircraft may be defined for the theater and used to offset the degradations due to lost or damaged aircraft, or aircraft with excessive maintenance requirements. This pool may be used in addition to, or instead of, a reserve of aircraft in CONUS. It is assumed that an air crew is available for each aircraft in the pool. The user is provided options as to how these aircraft are used and managed. Whenever a filler aircraft is assigned to a combat unit to replace a combat loss, a replacement is ordered from CONUS, if stipulated by the replacement policies that the user has prescribed.

Aircraft Transfer and Diversion Decisions

The basic evidence needed to reach these decisions is estimates of each base's capability to generate sorties of different kinds with the different aircraft types. Naturally, one cannot expect to obtain such estimates with anything like the accuracy achieved in the simulation proper, but that simulation can only indicate the sorties that have been flown during a previous period, for a particular set of aircraft and flight demands. To obtain more general estimates TSAR incorporates a procedure that provides approximate assessments of the air-

base capabilities used to support such decisions. The estimates developed with this procedure are updated daily and are derived to capture the effects of resource shortages that result from either consumption or base damage.

The substantial processing required to develop these projections is conducted only when specified by the user. There are two steps in the procedure: The first is conducted at program initialization and generates the expected resource requirements per sortie for each type of aircraft on each type of mission. These requirements include the expected manhours for each type of personnel, the expected utilization of each kind of equipment, part, and munitions, and the likelihood that any of the shop facilities will be required.

The second step of the procedure is to compare the on-base assets with the per-sortie requirements for each type of resource. This is done by dividing the assets by the sortie requirement and interpreting the result as the constraint imposed on sorties by that type of resource. The lower bound of all such constraints is determined for each type of aircraft and for each type of mission. The calculations are carried out daily at 1930 just before the sortie demand data are input and scheduled.

The actual computations are somewhat more complicated than just outlined for several reasons. For the mission-dependent munitions, the calculation takes into account whatever lower priority combat loads could be loaded, as well as the preferred SCL; for parts, the projection is modified to account for the serviceable items that would be expected to be generated by parts repair. Furthermore, three different projections are derived: The first projection is made without regard to the number of aircraft on base; the second projection introduces the additional constraint that no more than NS sorties may be flown, where N is the number of aircraft of the type considered that do not have mission-critical "holes," and S is the maximum number of sorties that an aircraft could fly during a day.

The third projection provides an approximate accounting for other aircraft types that may be on base and that have common resource demands. The base's capabilility to generate sorties with each type of aircraft is determined by dividing the level of available assets by the aggregate demand of all aircraft types for each kind of resource (where the demands are weighted by the number of aircraft of each type).

These three projections are stored for each base, each aircraft type, and each type of mission. It is the data in these arrays that provide the basis for the various aircraft management decisions during the ensuing 24 hour period.

PERIODIC REVIEW AND REALLOCATION OF RESOURCES

The available numbers of ground personnel, equipment, and serviceable aircraft parts may be reviewed periodically, and actions may be taken to redress whatever serious imbalances are noted. The user controls the nature and timing of these reviews. The information used for these reviews is the delayed and imperfect status data reported to the theater manager by the theater communications system.

Ground Personnel

For each type of personnel, TSAR first establishes which base's staff has the largest and the smallest proportion of their nominal complement (adjusted for the actual aircraft on hand), and then sends 20 percent of that type of personnel from the best staffed base to the

worst, when certain conditions are met. To wit:

1. The gaining base has less than 75 percent of its nominal requirement.
2. The losing base has more than half its nominal requirement, and
3. The losing base has over twice as many staff members, proportionately, as the gaining base.

The adjustment for the actual number of aircraft on hand, consists of multiplying each base's nominal, or "target," number for each type of ground personnel by the present number of aircraft, and dividing by the original number of aircraft.

Ground Support Equipment

The logic applied to each type of support equipment at each base is identical to that used for reallocating ground personnel.

Aircraft Parts

When parts are reviewed, TSAR checks on whether there are more parts of each type in the central supply than were specified to be held in reserve (by the user's initialization of the nominal or "target" level at the CIRF). If there are, TSAR checks on which base has the greatest need, and the parts are shipped one at a time until the surplus is exhausted.

To determine which base is to receive a part, the operating bases are each checked and the total number of assets of that type of part on each base is determined by summing the serviceable items, those enroute, and the reparables (when the base's repair shop is functioning). That number is then reduced by the number of aircraft needing that part on that base; the result is divided by the base's nominal requirement for that part (adjusted for the number of aircraft on base). The final result is interpreted as the relative availability of that part type on that base, and a part is shipped to the base with the numerically lowest value of relative availability. This process is repeated until there are no parts of that type at the central supply point in excess of the specified reserve; the whole process is then repeated for the next type of part.

ACQUISITION OF SPARE PARTS

Whenever an aircraft "hole" is reported, that aircraft's operating base may, under certain conditions, request and, if other conditions are fulfilled, obtain a spare part from another operating base, or from the theater's central supply. The procedures used are controlled by the user's choice for appropriate control variables, that also control the rules governing the disposition of newly repaired and newly acquired parts at the central supply point. The procedures adopted are summarized in Table 2.

The procedures and conditions that govern the five different responses to a base request follow:

When CCIRF = 1, a simple mode of lateral resupply is simulated. Whenever a "hole" is reported, the bases that the user has specified are checked one by one, and the first base that fills the specified conditions ships a part to the requesting base. Those conditions are, first, that the number of reparables minus the number of "holes" at the requesting base is less than

Table 2

PROCEDURES THAT GOVERN THE ACQUISITION AND DISPOSITION OF SPARE PARTS

Value of Control Variable CCIRF	Response to Parts Requests	Central Supply Policy For Reparables and Depot Resupply
0	No response	Return to sender
1	Lateral resupply requests filled by first base fulfilling conditions	Return to sender
2	Lateral resupply requests filled by base best fulfilling conditions	Return to sender
3	Parts requests filled by central supply when conditions permit; otherwise same as 1	Retain in stock
4	Parts requests filled by central supply when conditions permit; otherwise same as 2	Retain in stock
5	Same as 3	Send to most needy base if in excess of required reserve
6	Same as 4	Same as 5
7	Parts requests filled by central supply when conditions permit; otherwise they direct lateral resupply	Same as 5

the value of ORDER2 and, second, that either the other base has at least two serviceable parts, or that base has only one serviceable part, but its nominal stock level, when adjusted for the residual number of aircraft, is less than one-quarter of a part.

When CCIRF = 2, the procedures parallel those for CCIRF = 1, except that all bases are checked and the base with the largest number of serviceable parts is chosen; if that base has only one serviceable part, the current value of its nominal stock level must again be less than one-quarter of a part.

For values of CCIRF greater than 2, the first action taken by the ordering base is to check whether the theater's central supply has a part that may be shipped. If there is a serviceable part at the central supply point it is shipped if the requesting base fulfills the following condition: The sum of the ordering base's number of reparables, plus the number of serviceables already enroute from the central supply, minus the number of "holes" in aircraft at that base, must be less than the value of ORDER1.

If a part is not shipped by central supply, the requesting base then attempts to obtain a part from an operating base by a lateral resupply action. For CCIRF = 3 and 5, the same procedure is used as when CCIRF = 1. For CCIRF = 4 and 6, the procedure is that used when CCIRF = 2.

When a part cannot be shipped by the CIRF, and CCIRF = 7, the central manager checks the other operating bases to determine which can best afford to ship a part to the requesting base. This check of the other bases is based on the status information as reported through the theater reporting system. To select the donor base the following ratio is comput-

ed for all other bases: [available parts plus enroute parts] divided by [the current level of the nominal base requirement]. The base with the largest value for this ratio is directed to ship a part to the requesting base if that value is greater than one-quarter. If it is not, but there are at least two serviceable parts at that base, one is shipped.

DISPOSITION OF NEWLY REPAIRED OR NEWLY ACQUIRED PARTS AT A CENTRAL SUPPLY POINT

As outlined above, three options are available for disposing of newly acquired serviceable parts at the theater control supply point. For CCIRF = 0, 1, and 2, newly repaired parts are returned to the base at which the reparable was generated; newly acquired parts are placed into the local stock. For CCIRF = 3 and 4 all such serviceables are placed into stock at the central supply point.

For CCIRF = 5, 6, and 7, any newly acquired part that is in excess of the central supply's stipulated reserve is shipped to the most needy base. That determination is made in the same manner that was outlined in conjunction with periodic resource reallocations; that is, it is sent to the base with the lowest ratio of [serviceables + reparables + enroute − "holes"] divided by the base's current nominal requirement. These calculations are based upon the status information reported by the theater reporting system.

REPAIR PRIORITY DETERMINATION AT A CIRF

When broken parts must wait to be repaired at an operating base, their position in the appropriate shop's wait queue is based upon the local supply and demand, and they are ordered as outlined in Sec. VII. At a centralized repair facility somewhat different procedures naturally must be followed when parts are to be ordered (other than FIFO), since there is no local demand as such. Interrupted repairs are given priority over waiting repairs when resources become available, on the assumption that if they were sufficiently important to have been started, they should be finished. But when resources are available and no interrupted repairs are queued, the parts that have been waiting are checked to see which should receive attention. Actually the prioritization of waiting parts at a CIRF is a two-step process; one set of rules governs the order in which parts are placed into the wait queue and the second governs the criteria that must be satisfied when a part is withdrawn from the queue. The primary purpose of the first of these two procedures is to limit the processing required for carrying out the second procedure.

Whenever a reparable part concludes the administrative delay at a CIRF and must wait to be repaired, it is ordered so that parts that are important, are needed, and can be quickly repaired receive priority. This ranking takes into account all aircraft types that use that particular type of part, and the importance of that part to the missions that those types of aircraft can fly.

When repair personnel or equipment are released at the completion of another job, two sets of rules may be used for selecting the next part that will be repaired. For either of the options, an empirical estimate is made of the demand outstanding for the first item in the queue, and, if the value of that estimate is greater than a threshold variable, the repair is initiated without checking any further. If it is not, the next part is checked, etc. If the value for none of the parts exceeds the threshold, the one with the highest value is initiated.

The manner in which the demand outstanding for a given part is estimated in the first instance takes into account the number of aircraft that require the part and the part's importance. In the second case, the estimate of demand takes into account both the current backlog of repairs and the expected future demands for parts, based on the present pattern of sortie demands. This is done by expressing demand as proportional to the sum of (1) a fraction of the existing number of "holes," and (2) the number of "critical holes" that would be expected to develop if the current sortie demands continued to be flown for the length of time that it would take to ship a part to an operating base.

XII. OUTPUT

In a simulation that involves multiple trials and as wide a variety of activities as TSAR, there is a great abundance of data that might be reported. The output options that are provided with TSAR permit the user to examine a large number of aspects of the simulated operations, but all possible outputs are not available. If some users find a need for more specialized results, custom additions can easily be appended.

For the individual trials the data printed relates to the numbers of flights and sorties flown and the numbers of maintenance tasks accomplished. Shop performance statistics may be collected and displayed at a user-specified frequency, and they will include statistical data on the resource constraints that cause on-aircraft maintenance delays. Such data may be obtained separately for each trial, or the results may be accumulated over all trials. Another feature enables the user to observe the behavior of aircraft in some detail. When used, a record of the daily activities for each of 24 aircraft is listed at the end of each day for the number of days specified. The beginning and end of each flight and each on-equipment task is listed chronologically for each aircraft.

In addition to the various data that may be obtained for each trial, the final results also include a day-by-day record of the average number of sorties flown, and the standard deviation thereof, for each mission and for each base, when more than one trial is run.

OUTPUT CONTROLLED BY THE VARIABLE "PRINT"

The output data are controlled by the value that the user assigns the variable *PRINT*. Those data will include all items down to and including those listed for the assigned value in Table 3.

OUTPUT CONTROLLED BY THE VARIABLE "STATFQ"

When the user sets STATFQ to a value greater than zero, TSAR saves data on the duration of aircraft maintenance tasks, parts repair jobs, and aircraft maintenance delays. These data are printed at the end of each STATFQ day, at the end of each trial, and at the end of the simulation. In each case, the results are based on the data to that point in the simulation, cumulated independently for each trial. The results at the end of each trial also include the delay data for those activities that are still waiting, on the assumption that all delays end at that time.

These results are presented in three sets; the first set presents the number of activities and the average length and standard deviation of the time that they required, for on-equipment tasks and for off-equipment jobs at each shop on each base. The standard time, or resource unconstrained time, as calculated during the input process for each shop, is also listed for the on-equipment and off-equipment activities; the values computed for the various aircraft types are weighted in the output by the numbers of sorties flown by the various aircraft types at each base.

The second set of results provides a count of the ready aircraft that were canceled by a

Table 3

Output Data Controlled by the Variable "PRINT"

PRINT	OUTPUT DATA
-1	EOT: Storage array status if any overflows occur in one or more of the 18 dynamic storage arrays.
0	EOT: Cumulative flights and sorties flown, demanded, and the percentage of sorties flown of those demanded; totals for each base and each mission.[a] EOT: Cumulative on-equipment tasks, parts and equipment repairs by base and by shop. EOT: Readiness indices[b] and cumulative hours NMCS at each base.
1	EOT: Sorties flown, demanded, and the percentage of those demanded by base and mission, ordered by priority. EOD: Aircraft possessed, lost, damaged, fillers, reserves, and transferred. EOD: Sorties and damaged aircraft by base. EOT: Daily reports listed for PRINT = 2.
2	EOD: Sorties flown, demanded, and the percentage of those demanded that were flown by base and mission. EOD: On-equipment and off-equipment tasks completed during the day by base and by shop. EOD: Numbers of tasks and repairs being processed, and the numbers of tasks waiting by base and by shop. (Also listed at noon if PRINT = 3.) EOD: Status of AIS and dynamic storage, and spares shipments. EOT: Remaining supplies of munitions and spares. Number of NMCS aircraft by base every six hours. Numbers of aircraft possessed, damaged, and with one or more "holes" by base, at three hour intervals. Notice of the initiation of runway or taxiway repair.
3	EOD: Flights flown and demanded by mission and base. EOD: Numbers of sorties launched each hour at each airbase. EOD: Numbers of repairs waiting, tasks and repairs interrupted. EOD: Cumulative manhours on aircraft tasks, parts and equipment repairs by shop and by base. Current supply of munitions and spare parts at each base every six hours, and number of munitions by type each day. Notice of initiation of facility repairs.
4	The numbers of interrupted tasks and repairs at noon. Available munitions by type every six hours. Notice of completion of facility repairs.
5	Hourly listing of the number of aircraft waiting at each shop on each base.
6	Numbers of personnel, equipment, and parts for restricted types of these resources are listed at noon for each base.

EOT = end of trial
EOD = end of day

[a]Sortie data are available by base, aircraft type, mission, and priority.

[b]The readiness indices provide a cumulative measure of how quickly aircraft were prepared for flight. The index is the average percentage of each base's aircraft that were ready to fly within 2, 4, 6, and 8 hours after the previous sortie.

crew shortage and a count of the additional numbers of crews that would have been needed to satisfy the minimum flight requirements.

The last set of data provides a statistical summary of the causes and the duration of aircraft maintenance delays. For each base, for each of nine classes of resources, and for each individual resource type that caused an on-equipment task to be delayed, the results include the number of such delays and the average value and standard deviation of their duration. If any of the aircraft have "holes" at the time of the report, they are listed with the parts data for each base.

Data of these several types are listed only when there are results to be reported; null data are suppressed.

REFERENCES

1. Captain R. R. Fisher et al., "The Logistics Composite Model: An Overall View," The Rand Corporation, RM-5544-PR, May 1968.
2. T. C. Smith et al., "A User's Manual for SAMSOM II: The Support Availability Multi-System Operations Model," The Rand Corporation, RM-4923-PR, November 1967.
3. D. E. Emerson, *AIDA: An Airbase Damage Assessment Model*, The Rand Corporation, R-1872-PR, September 1976.
4. A. T. Kearney, Inc., "Airbase Model," AFATL-TR-78-25, Air Force Armament Laboratory, March 1978.
5. "TAC TURNER," Developed by AFSA for use with TAC WARRIOR.
6. "Air Base Vulnerability Models: Description and Conception of the Sortie Generation Model and Its Application," B-SO-2075/08 (Translation), IABG (Industrieanlagen-Betriebgesellschaft) GmbH, Munich.
7. "FORSCAP Sortie Generation," Developed by USAFE/XP.
8. Donald Emerson, "TSARINA—User's Guide to a Computer Model for Damage Assessment of Complex Airbase Targets," The Rand Corporation, N-1460-AF, July 1980.
9. D. E. Emerson, "TSAR User's Manual: Vol. I—Program Features, Logic and Interactions," The Rand Corporation, N-1820-AF, 1982.
10. D. E. Emerson, "TSAR User's Manual: Vol. II—Data Input, Program Redimensioning and Operation, and Sample Problem," The Rand Corporation, N-1821-AF, 1982.
11. D. E. Emerson, "TSAR User's Manual: Vol. III—Variables and Array Definitions, and Source Code Structural Aids," The Rand Corporation, N-1822-AF, 1982.
12. J. R. Gebman, N. Y. Moore, H. L. Shulman, with C. L. Batten, *Support for the F-15's Combat Avionics, Vol. I: A Summary of Deficiencies and Policies for Improvement*, The Rand Corporation, R-2591/1-AF, forthcoming.
13. J. R. Gebman, N. Y. Moore, and H. L. Shulman, *Support for the F-15's Avionics, Vol. II: An Analysis of Deficiencies and Policies for Improvement*, The Rand Corporation, R-2591/2-AF, forthcoming.
14. J. R. Gebman, N. Y. Moore, H. L. Shulman, G. M. Burkholz, L. Batchelder, P. A. Ebener, G. Halverson, P. Konoske-Dey, and S. Polich, *Support Resources for F-15 Avionics: Data Collection and Analysis Procedures*, The Rand Corporation, R-2611-AF, forthcoming.